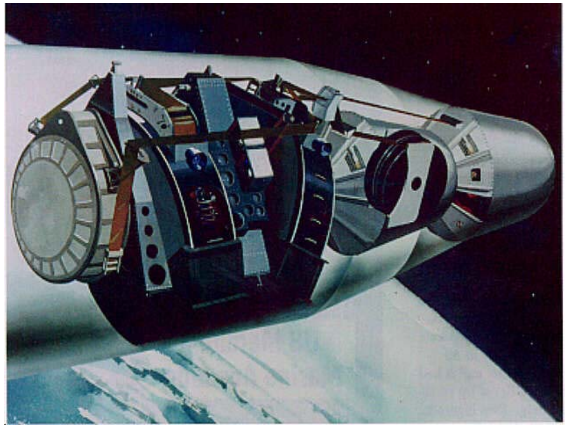
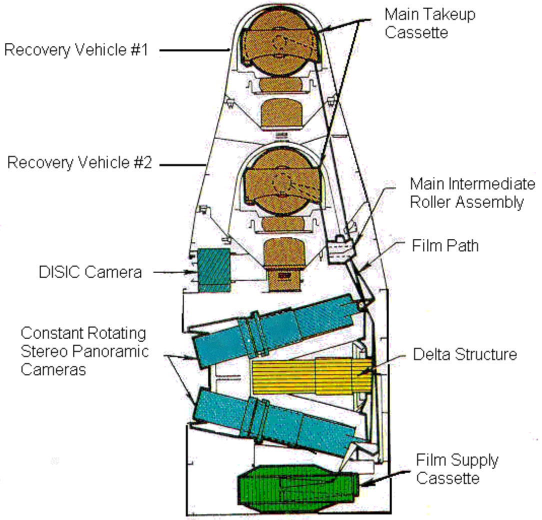
Remote Sensing
Chapter 3

Richard Christopher Olsen

Corona Satellite





KH4B, or J3 camera. DISIC=Dual Improved Stellar Index Camera

New York Times

"All the News That's Fit to Print"

The New York Times.

LATE CITY EDITION

U. S. Weather Bureau Report (Page 38) forecasts: Partly cloudy and warm today; fair tonight. Some cloudiness tomorrow. Temp. range: 80—63; yesterday: 71.2—59.4. Temp.-Hum. Index: low 70's; yesterday: 70.

VOL. CIX...No. 37,464. © 1960, by The New York Times Company. Times Square, New York 36, N. Y. NEW YORK, SATURDAY, AUGUST 20, 1960. 10 cents beyond 50-mile zone from New York City except on Long Island. Higher in air delivery cities. FIVE CENTS

SPACE CAPSULE IS CAUGHT IN MID-AIR BY U. S. PLANE ON RE-ENTRY FROM ORBIT

FLIERS ARE CITED

Vehicle Is Recovered 8,500 Feet Up in C-119's 'Trapeze'

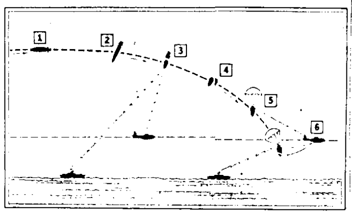
By The Associated Press.

HONOLULU, Aug. 19—A United States Air Force plane today caught a space capsule dropped from a satellite. A C-119 Flying Boxcar, on its third attempt, snared the eighty-four-pound capsule 8,500 feet over the Pacific Ocean.

The device that caught the capsule was a trapeze-like hook dangling from the plane's belly. It snared the shrouds of the parachute carrying the capsule toward the ocean.

The capsule had been ejected over Alaska by Discoverer XIV on its seventeenth orbit at 116 to 502 miles above the earth.

Capt. Harold E. Mitchell, 35 years old, of Bloomington, Ill. who was awarded the Distinguished Flying Cross imme-



The New York Times Aug. 20, 1960

RECOVERY: While orbiting earth (1), satellite is tilted by gas jets into re-entry position (2). Capsule is separated, slowed by retro-rocket (3) and started down (4). Then a parachute opens (5). The satellite's radio guides planes to scene, where one aircraft (6) snags capsule.

Russians Orbit a Satellite Carrying 2 Dogs and TV

By WALTER SULLIVAN
Special to The New York Times.

MOSCOW, Aug. 19—The Soviet Union launched an earth satellite today weighing more than five tons as an important step in its man-in-space program. On board, according to the announcement, were experimental animals

SECURITY COUNCIL MEETS TOMORROW ON CRISIS IN CONGO

Lumumba Lays 'Blackmail' to Hammarskjold, Who Assails Incidents

Two Hammarskjold documents will be found on Page 6.

By LINDESAY PARROTT
Special to The New York Times.

UNITED NATIONS, N. Y., Aug. 19—The Security Council was called today to meet at 12:30 P. M. Sunday in emergency session to consider the deepening crisis in the Congo.

The *summons was sent* by Armand Bérard of France, president for this month of the eleven-nation body. The Congolese delegation will be headed by Deputy Premier Antoine Gizenga, special representative of Premier Lumumba.

The Council meeting, originally scheduled tentatively for tomorrow, had been postponed for twenty-four hours to give the Congolese delegation time to confer with representatives from other African states before making their appearance at the Council table. As non-members, the delegation may speak but not vote in the Council.

Congolese Aides Arrive

POWERS GETS A 10-YEAR SENTENCE; SOVIET ASSERTS PENALTY IS MILD, BUT EISENHOWER FINDS IT SEVERE

U-2 TRIAL ENDED

3 Years to Be in Prison —Rest May Be Spent Working in Russia

Excerpts from pleas and text of the verdict, Page 2.

By OSGOOD CARUTHERS
Special to The New York Times.

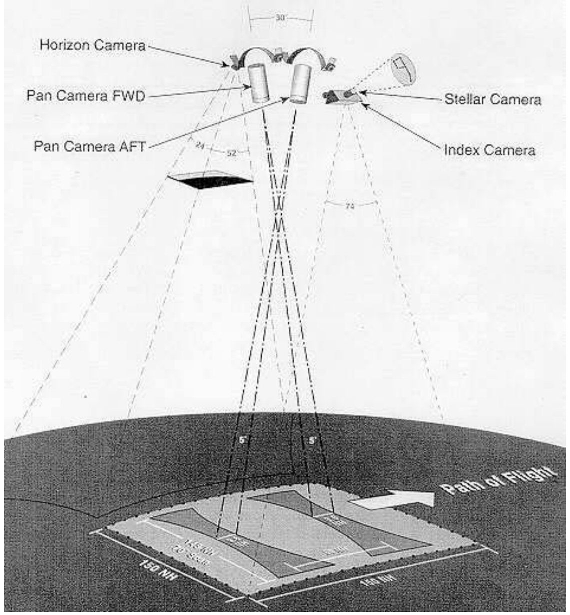
MOSCOW, Aug. 19—Francis Gary Powers was found guilty today of espionage for the United States and sentenced to ten years' loss of liberty.

The first three years will be spent in prison, the Soviet's highest military tribunal ordered.

This apparently meant that the pilot, who was 31 years old Wednesday, would be released from prison and sent to a remote and restricted area of the Soviet Union to work out the remaining seven years of the

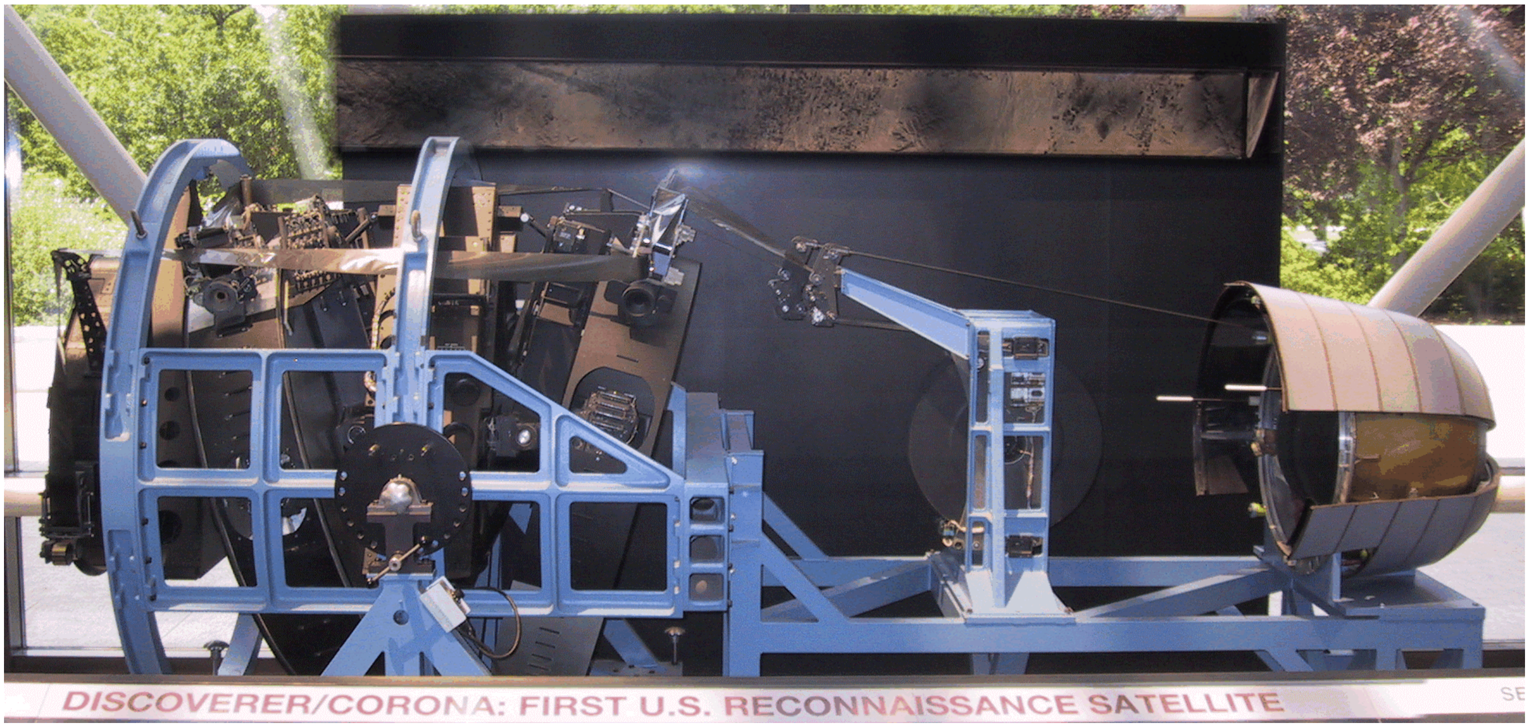
For comparison, GRAB, the first ELINT satellite, was launched June 23, 1960.

Imaging and Capture



A U.S. Air Force C-130 modified with poles, lines and winches extending from the rear cargo door captures a capsule ejected from a Discoverer satellite.

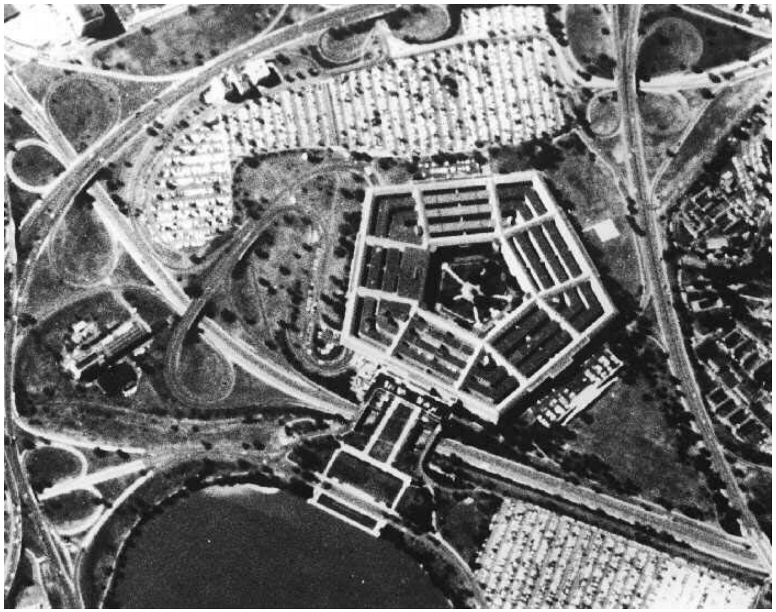
Corona - Smithsonian



First Picture from Space

Mys Shmidta Air Field, USSR. This August 18, 1960, photograph is the first intelligence target imaged from the first CORONA Mission. It shows a military airfield near Mys Schmidta on the Chukchi Sea in far-northeastern Russia.

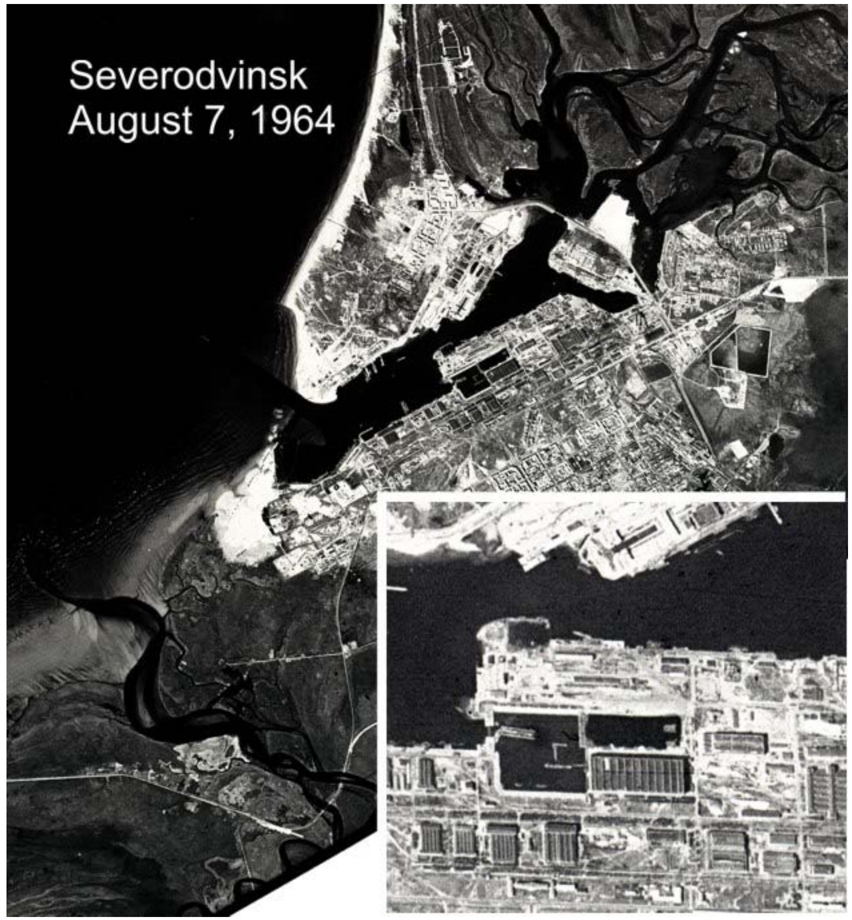
Corona Images of Washington DC



The Pentagon

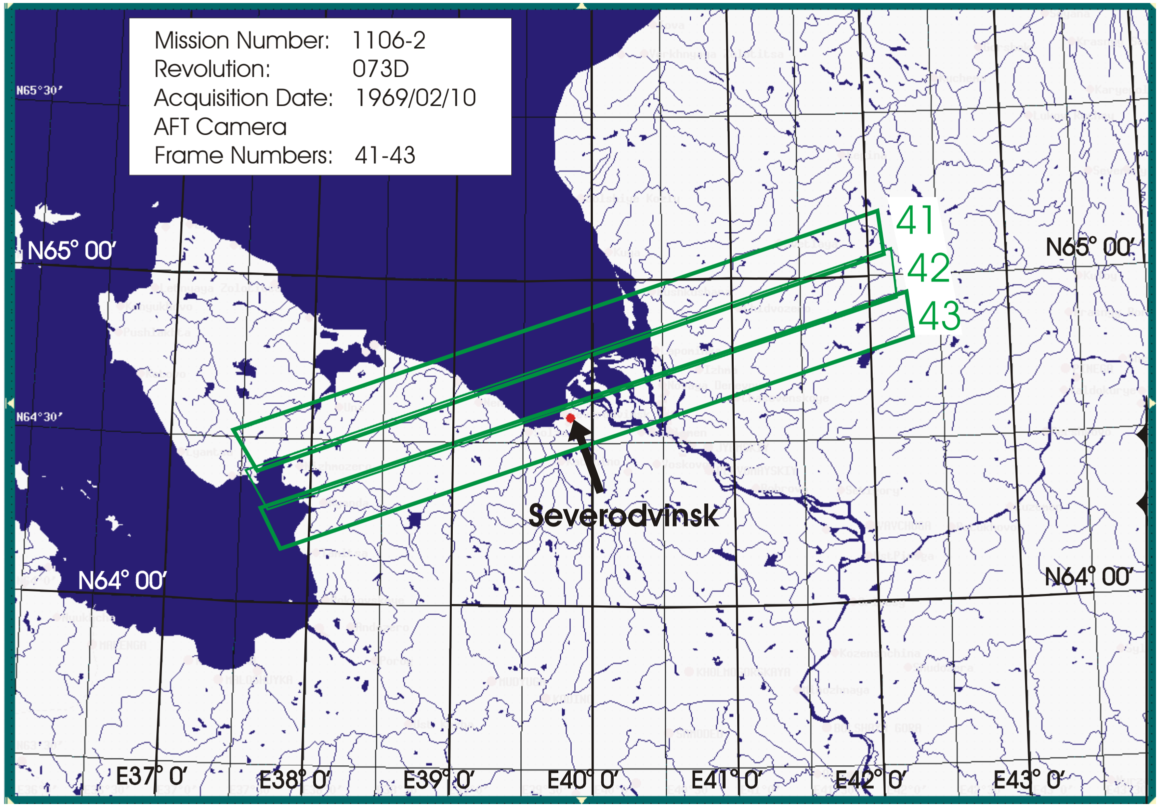
Washington Monument

Corona - Severodvinsk



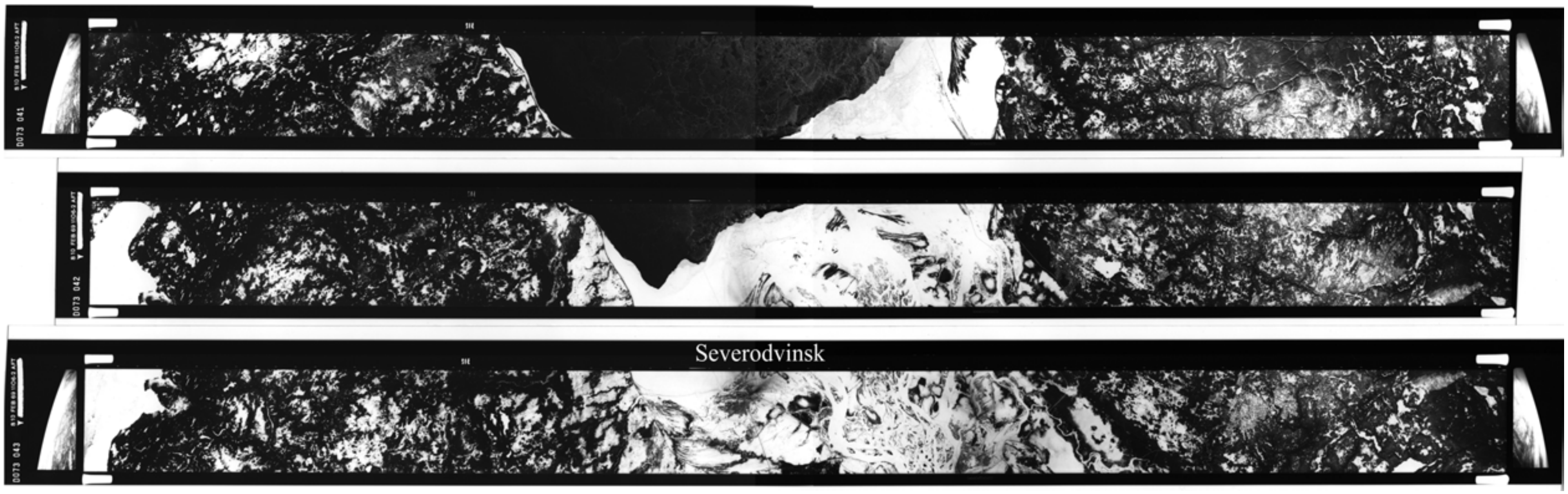
Severodvinsk Shipyard, August 7, 1964

Severodvinsk Map



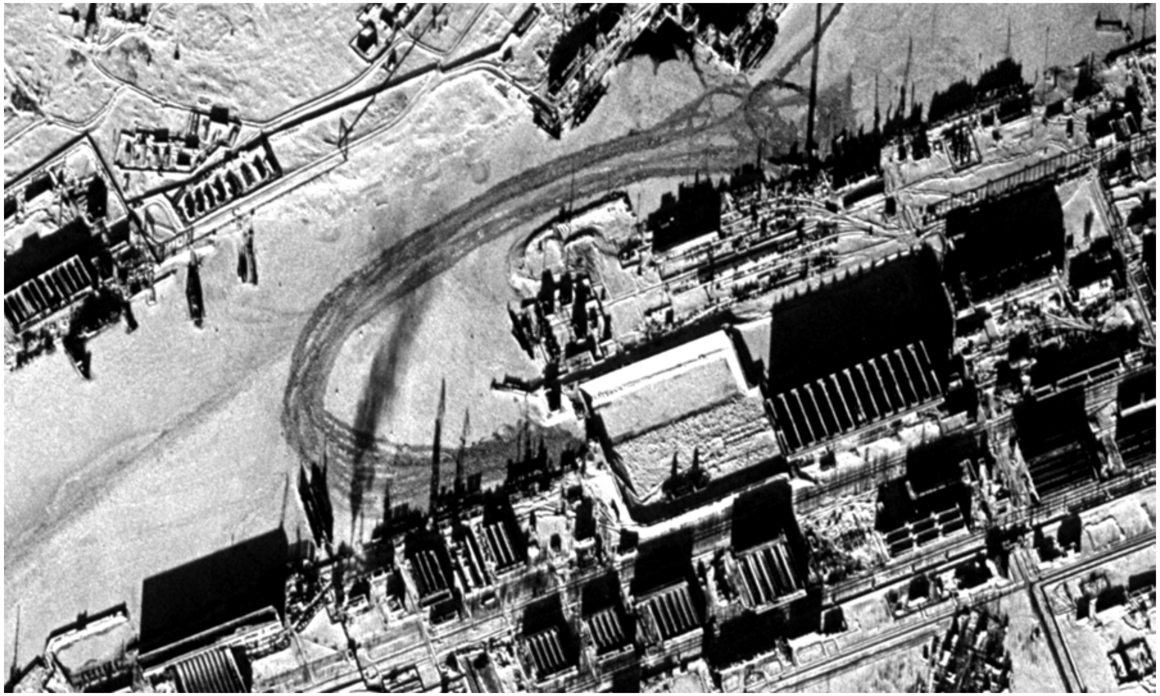
- Ground tracks for three consecutive images

Severodvinsk Film Strips



- Three consecutive Corona images. The shipyard illustrated above is in the third frame, in the middle, just under the word Severodvinsk.
- Note the extremely large area covered by each image

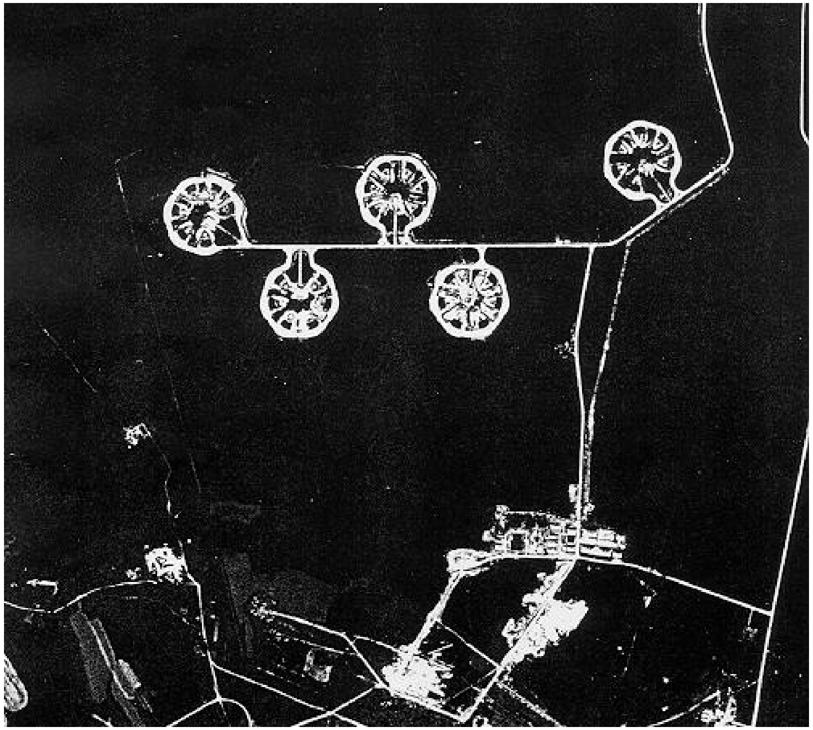
Corona - Severodvinsk



Severodvinsk Shipyard, February 10, 1969

AOB

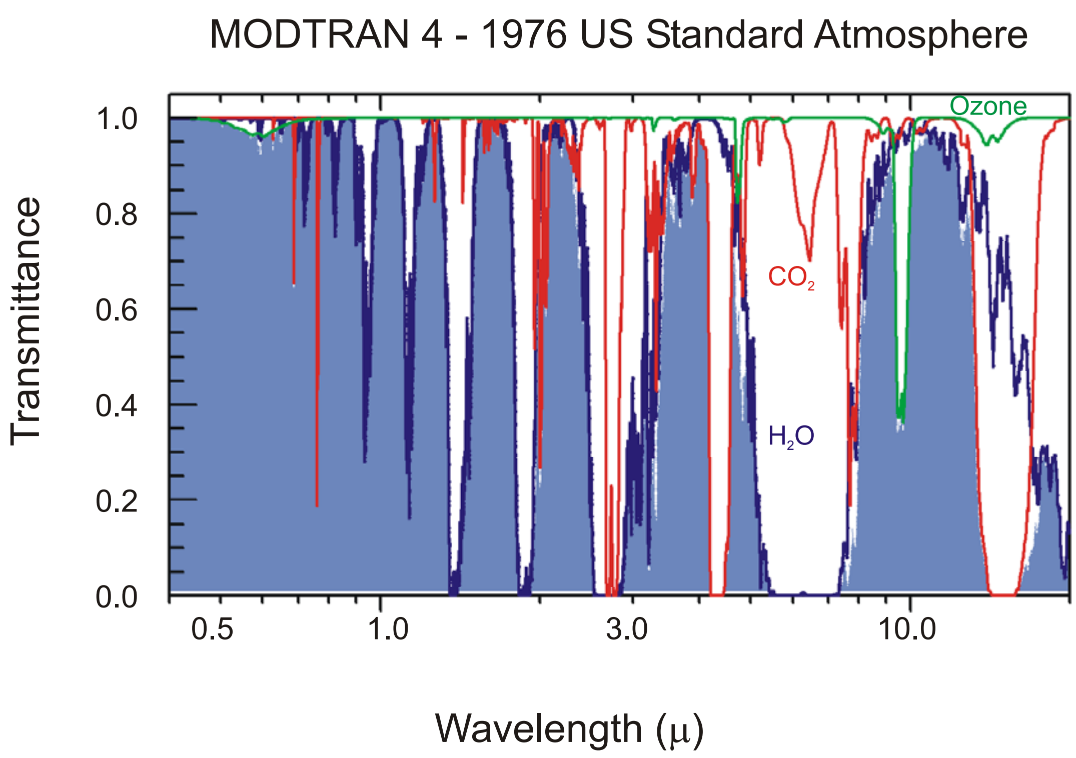
Pattern



Atmospheric Effects on Remote Sensing

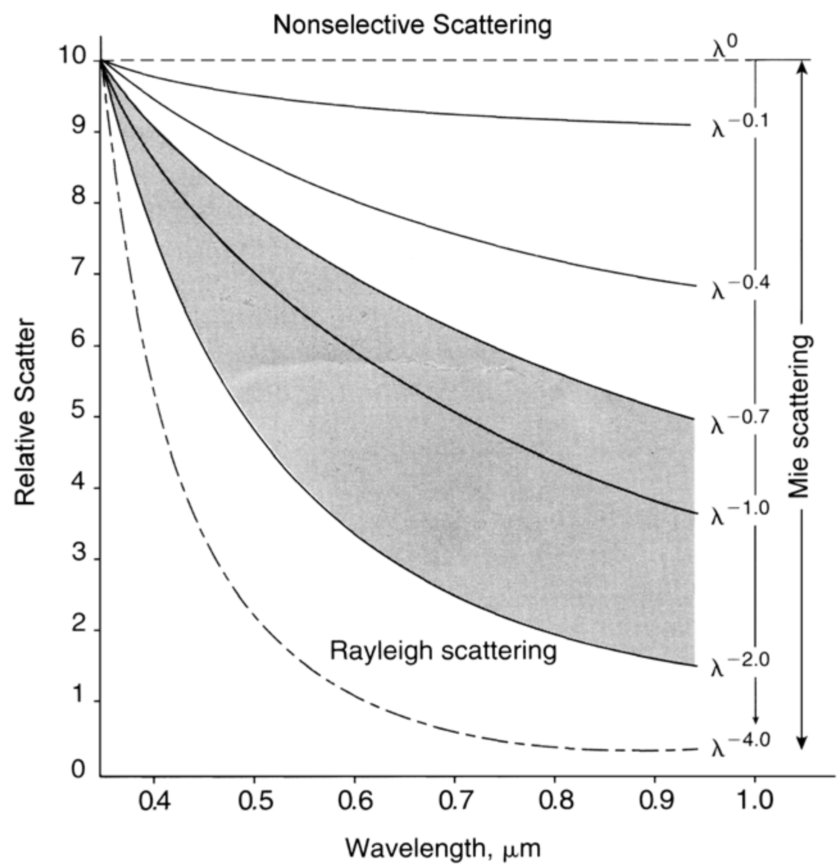
- Absorption
- Scattering
- Turbulence

Atmospheric Absorption

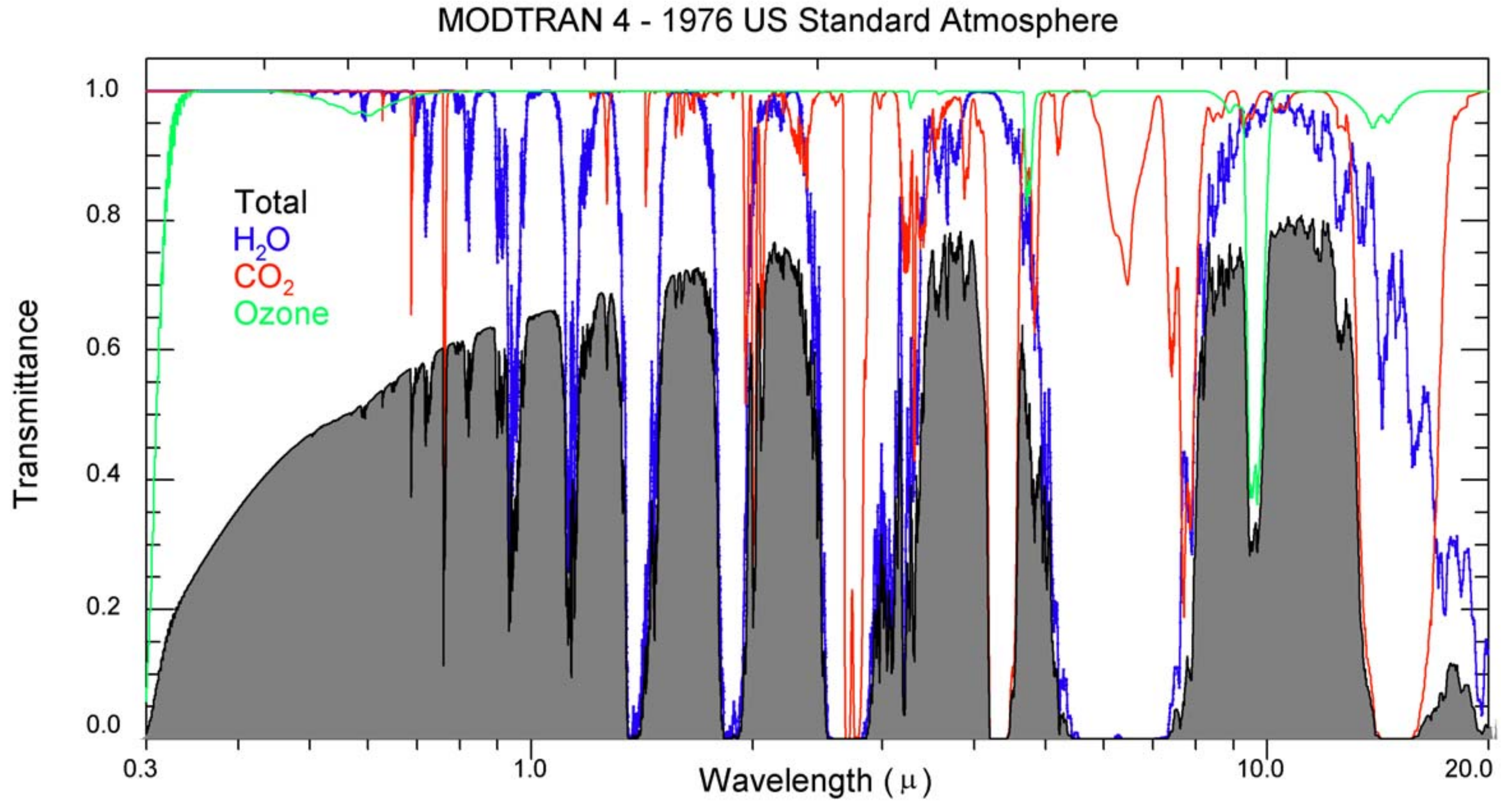


Atmospheric Scattering

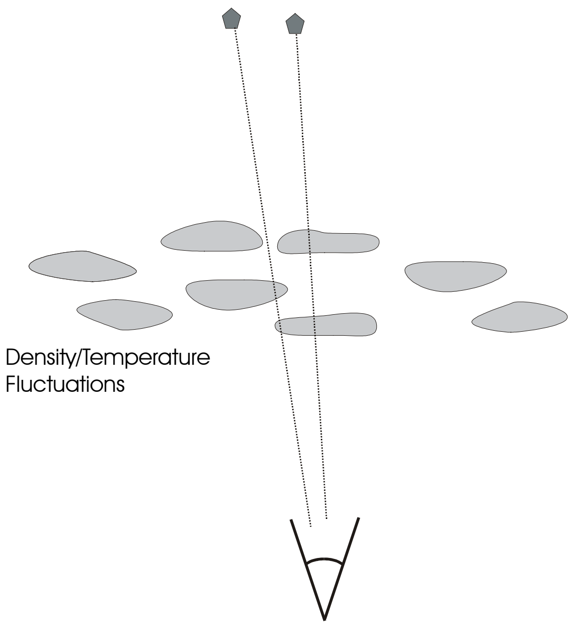
This is why you put a light yellow filter on a camera when you use a long telephoto lens to take a black & white photograph of some distant target



Scattering and Absorption

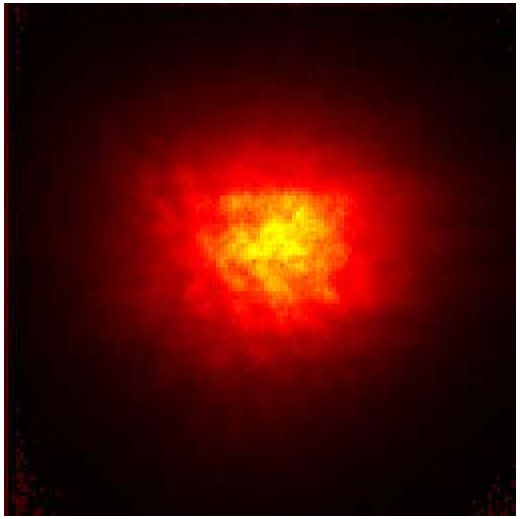


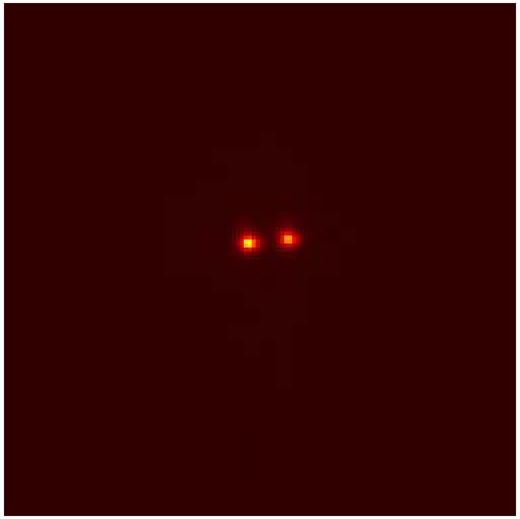
Atmospheric Turbulence



Canada-France-HawaiiTelescope

Turbulence Effects





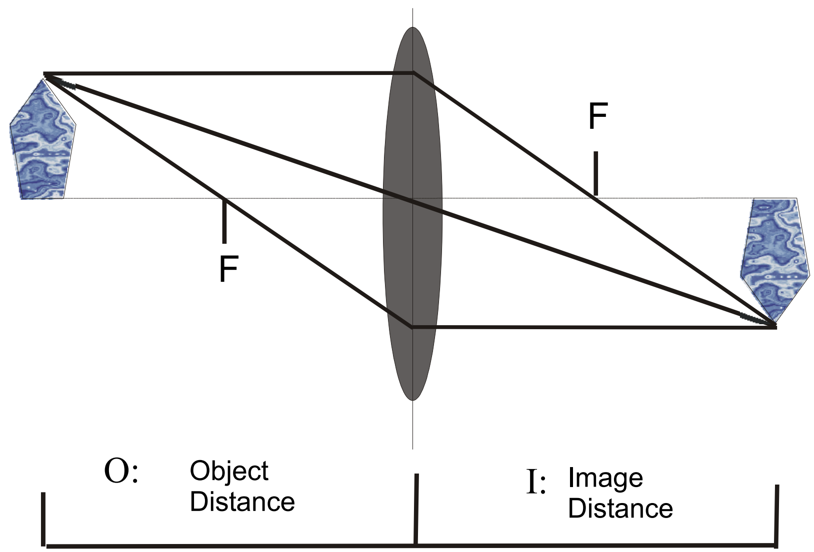
First light for the adaptive optics system on the 3.5-m telescope at the Starfire Optical Range occurred in September, 1997. This astronomical I Band (850 nm) compensated image of the binary star Kappa-Pegasus (k-peg) was generated using the 756 active actuator adaptive optics system. The two stars are separated by 1.4544 μradians (4.85 μradians/arcsecond).

The images are 128x128 pixels - each pixel subtends 120 nano-radians, or 3.17 arcsec. The FWHM of the uncompensated spot is about 7.5 μradians - about 5 times the separation of the two stars.

OPTICS

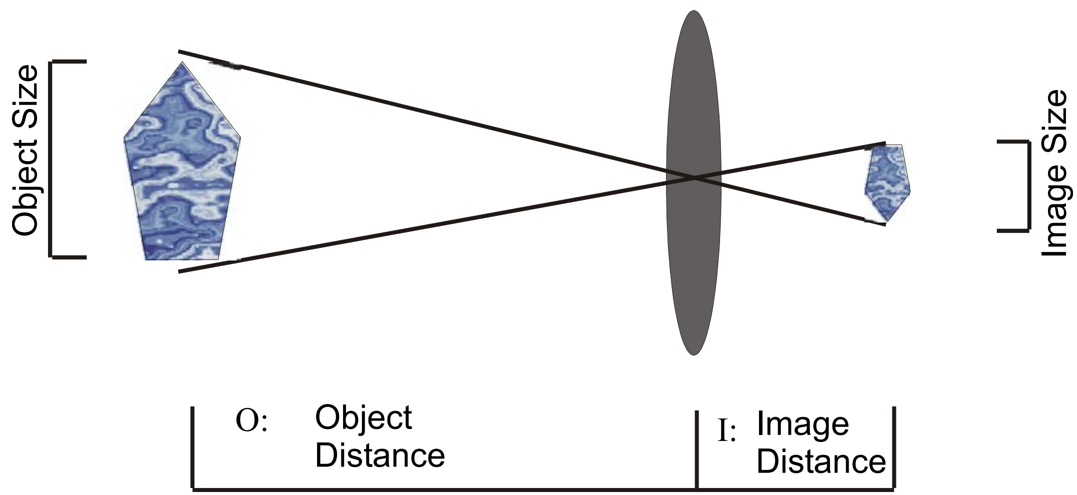
- The optical system for sensors that work in the visible and IR have two defining characteristics which determine their performance
  - – Geometrical Optics
  - – Physical Optics

Thin Lens Equation



$$\frac{1}{f} = \frac{1}{i} + \frac{1}{o}$$

Similar Triangles



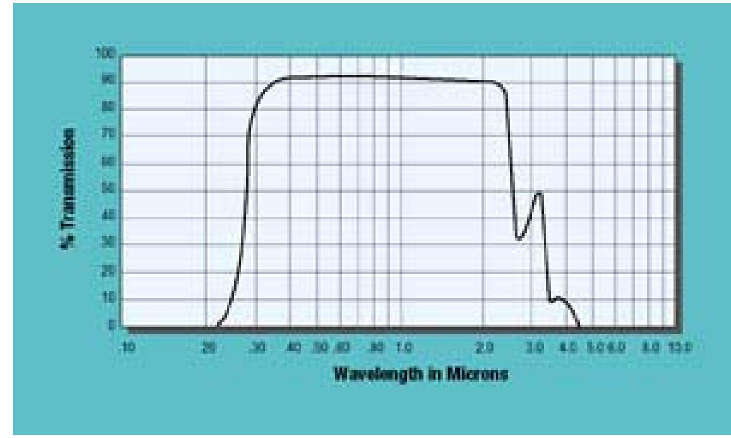
Lenses and Pinholes

Picture taken with 50mm “normal” lens, f/11, 1/500 s

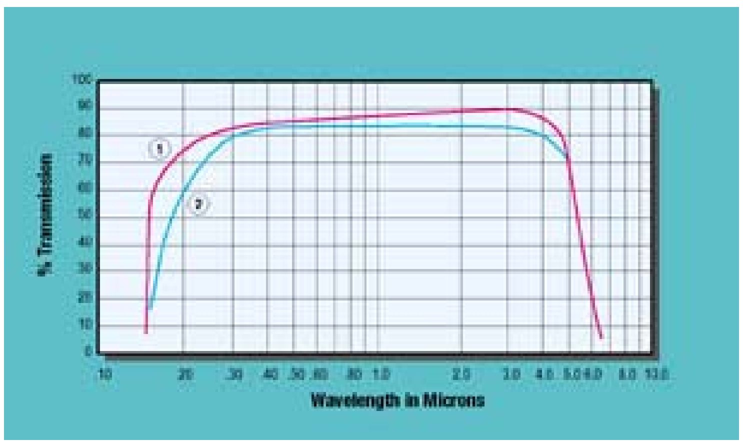
Picture taken with pinhole 0.57mm; ~ f/100, 1/30 s

Lens Materials

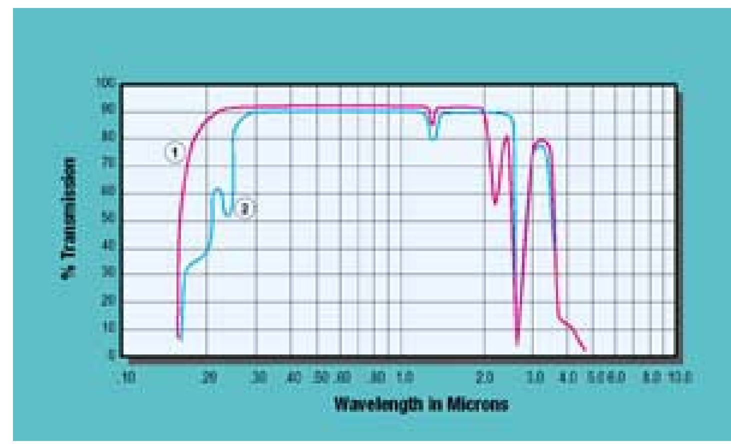
- One thing that limits the design of optical systems is the lens material. Materials which are transparent in the visible may not be in the IR, for example.



Glass Transmission Curve
1 mm thick reflection losses included
7056 Borosilicate

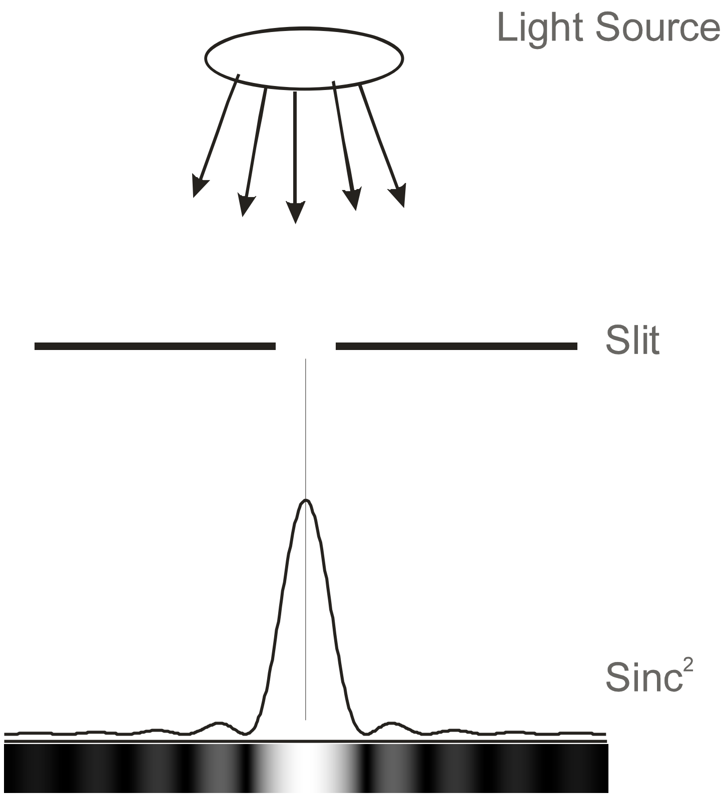


Sapphire Transmission Curve
1 mm thick reflection losses included
(1) UV Grade
(2) Regular Grade



Quartz Transmission Curve
10 mm thick reflection losses included
(1) UV Grade Fused Silica
(2) Regular Grade Fused Quartz

Interference Pattern from a Finite Aperture



In one dimension, for an infinite slit, the intensity is proportional to $\text{sinc}^2\ \alpha$ where $\alpha = \dfrac{2\pi\ \text{a}}{\lambda}\theta$.

a = slit width
λ= wavelength
θ=angle

Diffraction Pattern from a Circular Aperture

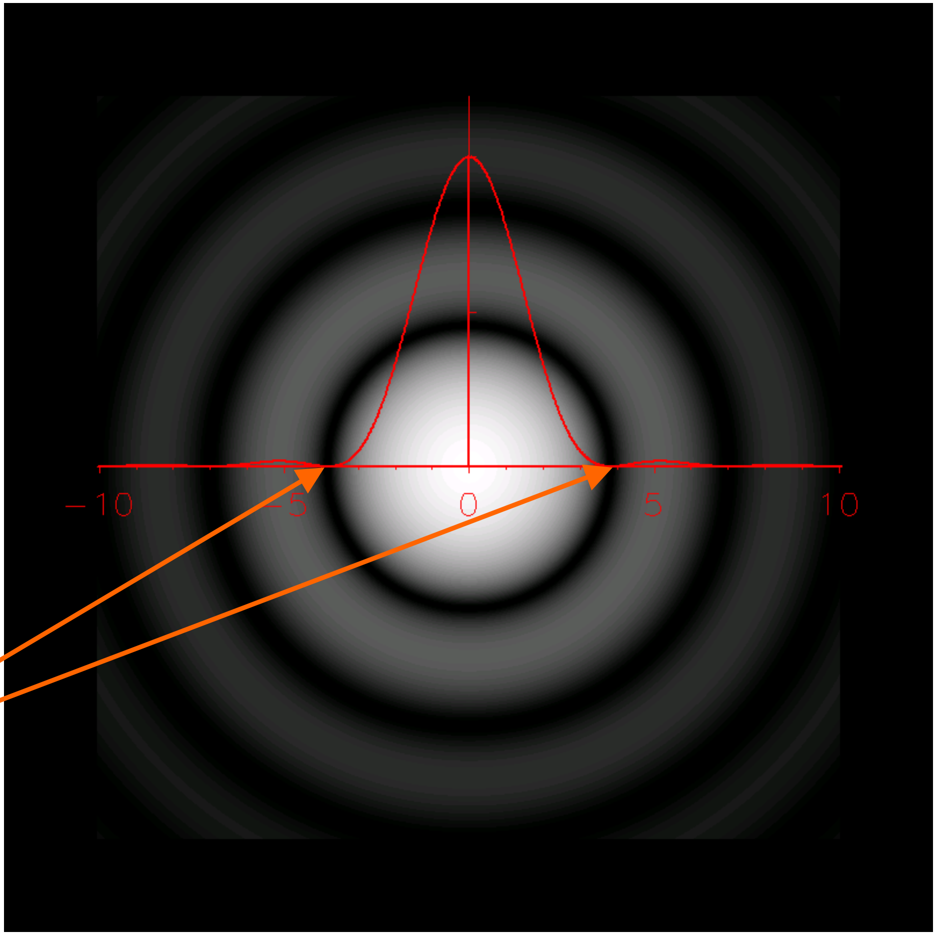
$$I \propto \left[\frac{J_1(w)}{w}\right]^2,$$

$$w = 2\pi \frac{a}{\lambda}\theta$$

J_1=the 'J' Bessel function of order 1.
a = lens radius,
θ = the angle subtended by the image
λ = wavelength.

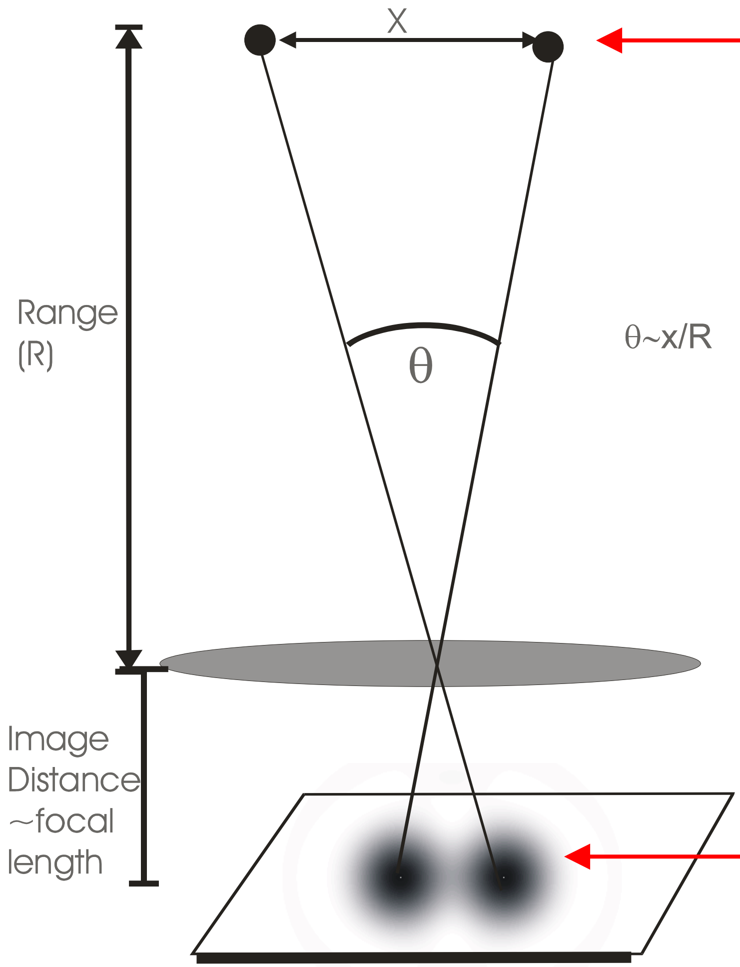
$$J_1(w) = 0 \text{ for}$$

$$w = 3.832$$



So the width of the beam pattern is $\Delta\theta = 1.22\ \lambda/a$

How does diffraction determine resolution ?



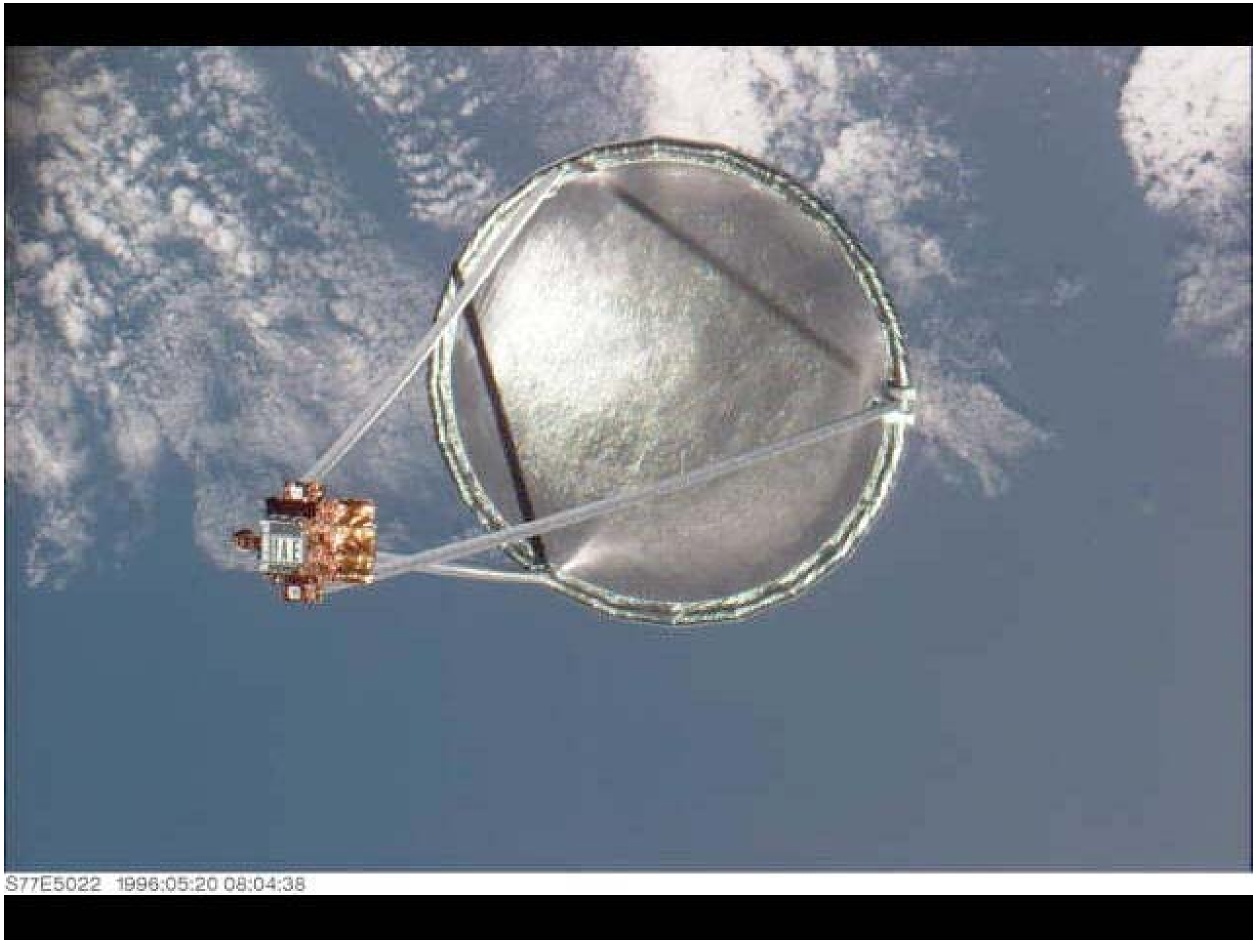
Two "stars" separated by a distance x

They form images which are spread out by the diffraction associated with the optical aperture (the diameter of the lens or mirror. They have to be separated by an angular distance defined by the Rayleigh criteria:

$$\Delta\theta \approx \frac{\lambda}{D}$$

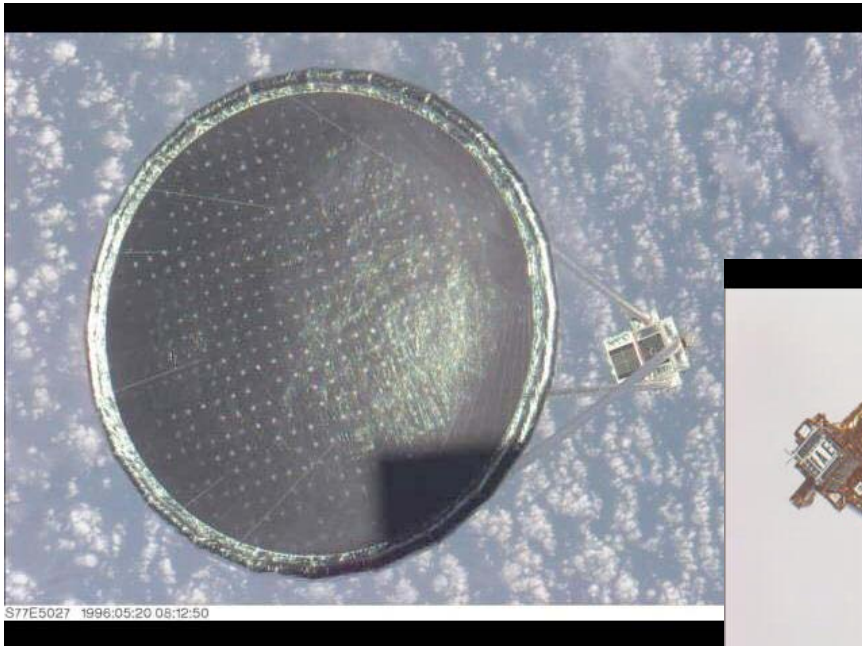
Diffraction patterns and resolution

STS-77 – Spartan 207

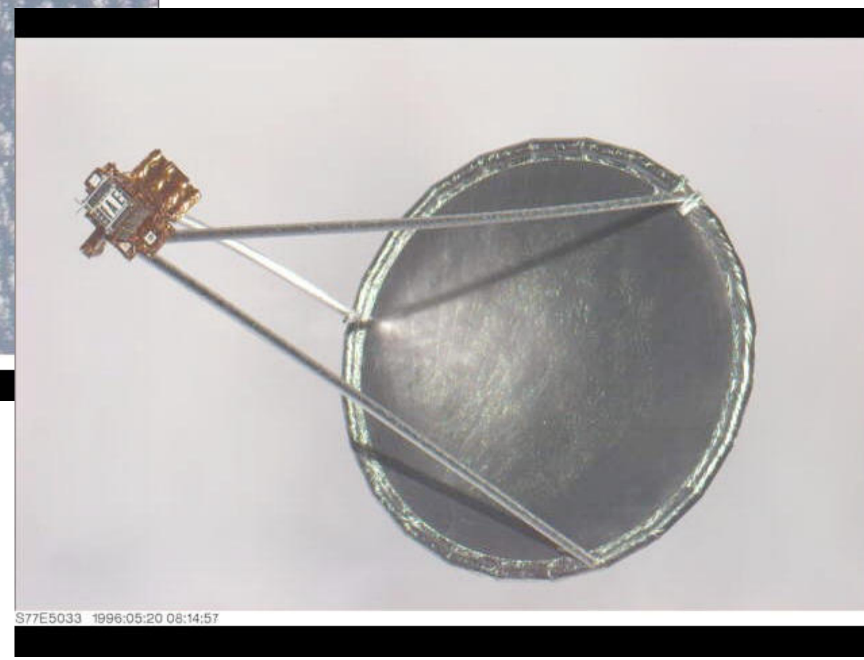


50 feet in diameter (14 meters)

STS-77 5/20/96

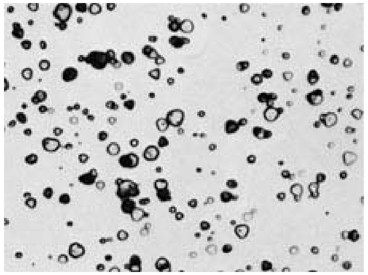


NASA Photo ID: s77e5027 Title: Following its deployment from the Space Shuttle Endeavour, the Spartan 207/Inflatable Antenna Experiment (IAE) payload is back dropped over clouds and water. Description:
Following its deployment from the Space Shuttle Endeavour, the Spartan 207/Inflatable Antenna Experiment (IAE) payload is backdropped over clouds and water. GMT: 08:12:50.

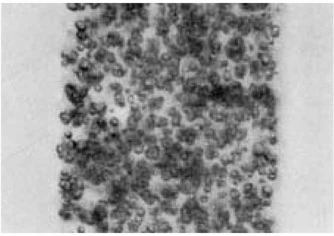


NASA Photo ID: s77e5033 Following its deployment from the Space Shuttle Endeavour, the Spartan 207/Inflatable Antenna Experiment (IAE) payload is backdropped against a wall of grayish clouds.

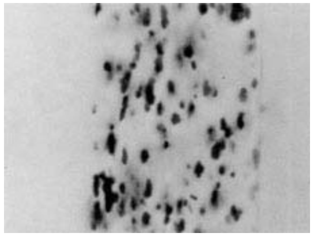
Grain in Film



The silver bromide grains of an x-ray film emulsion (2,500 diameters). These grains have been dispersed to show their shape and relative sizes more clearly. In an actual coating, the crystals are much more closely packed.

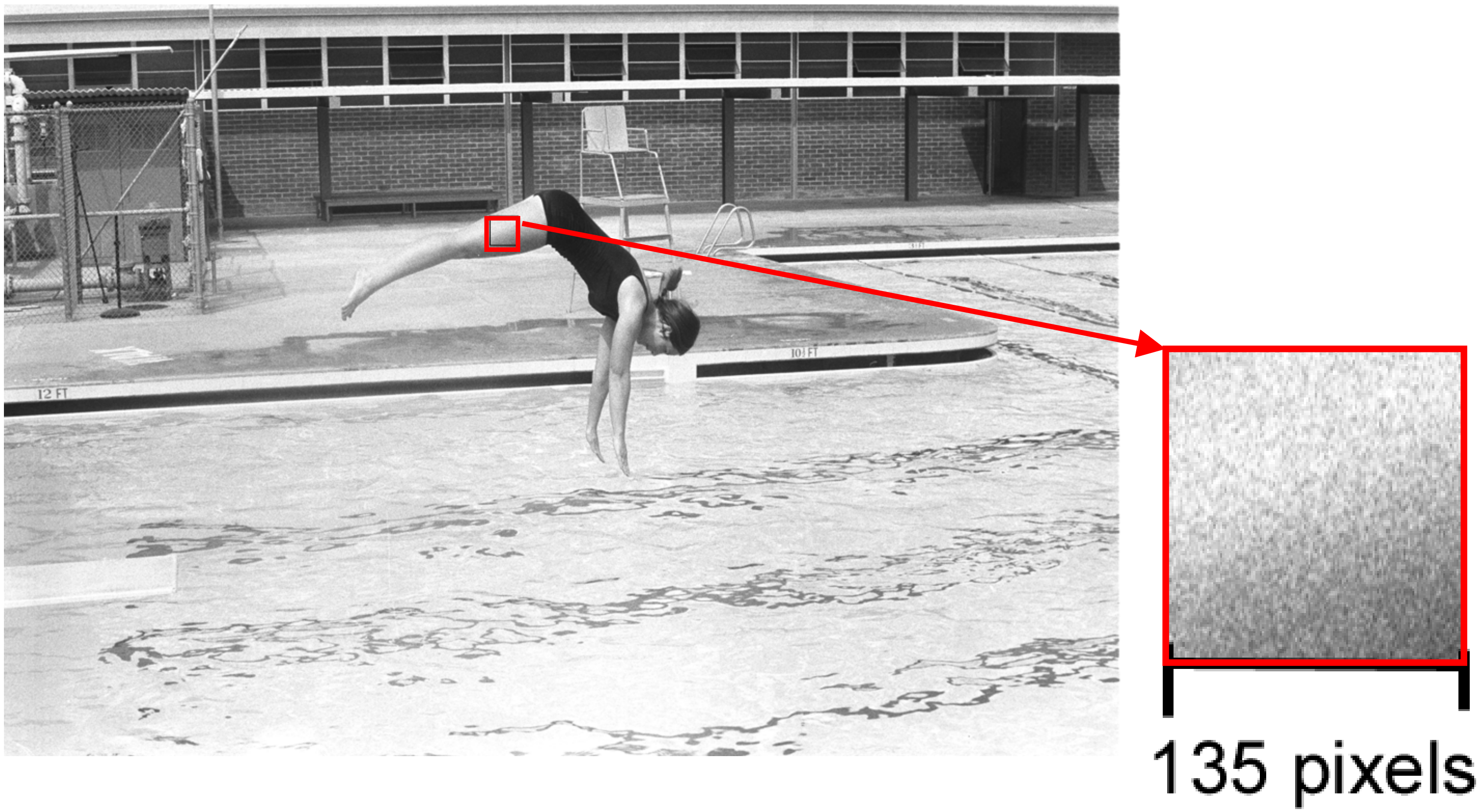


Cross section of the unprocessed emulsion on one side of an x-ray film. Note the large number of grains as compared to the developed grains of the figure to the right.

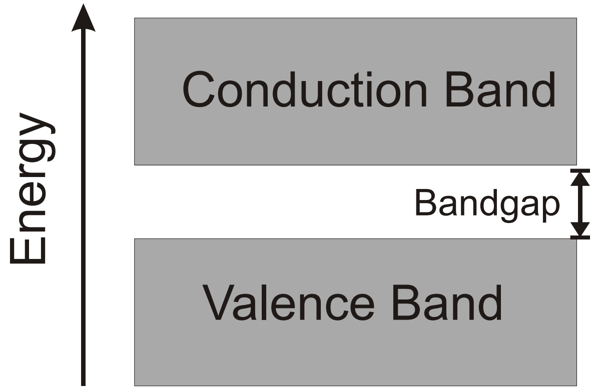


Cross section showing the distribution of the developed grains in an x-ray film emulsion exposed to give a moderate density.

Grain in Film - 2



Solid State Detectors



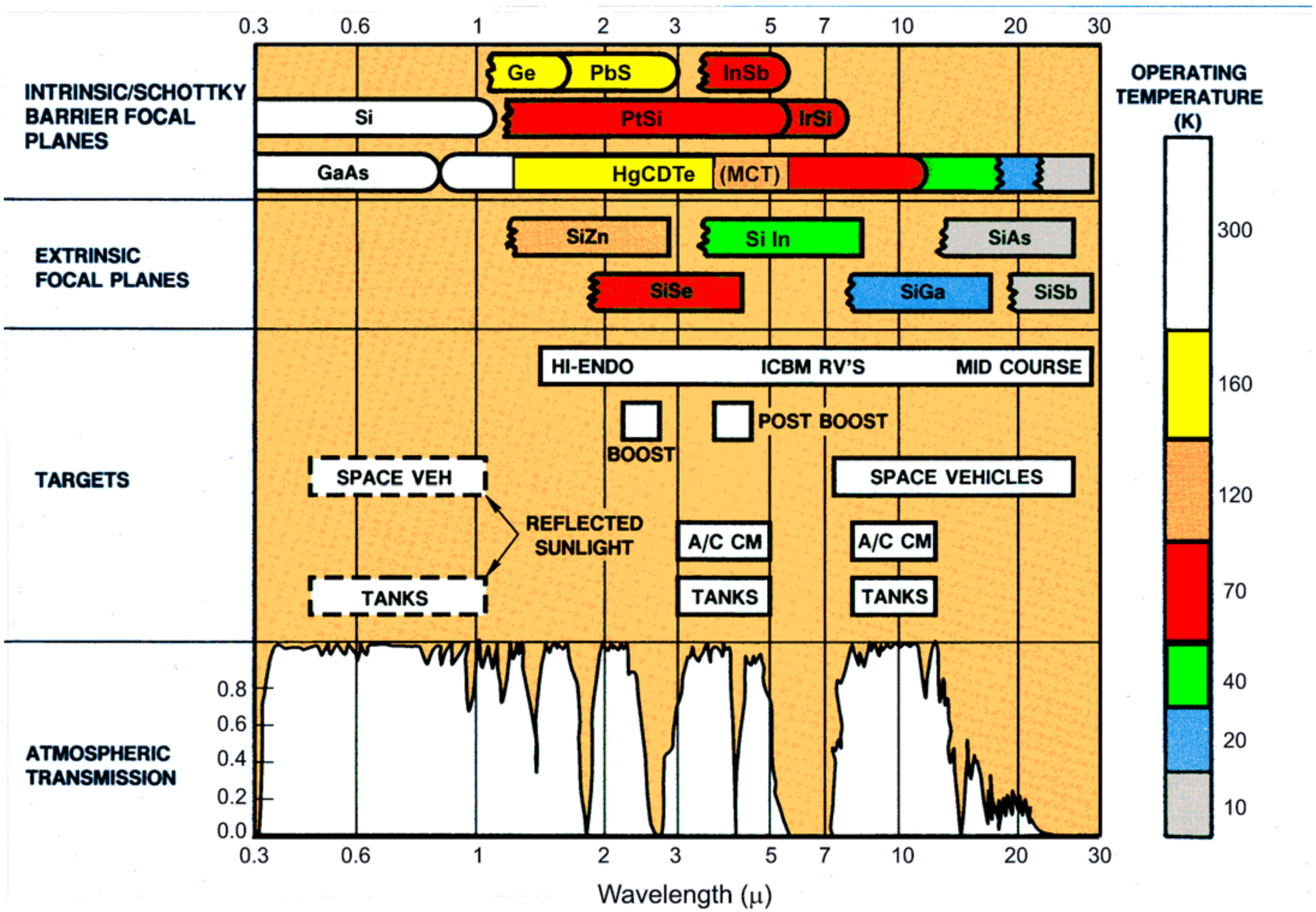
Linear KLI-8023

The KODAK KLI-8023 Image Sensor is a multispectral, linear solid state image sensor for color scanning applications where ultra-high resolution is required. The imager consists of three parallel linear photodiode arrays, each with 8000 active photosites for the output of R, G, and B signals. This device offers high sensitivity, high data rates, low noise and negligible lag. Individual electronic exposure control for each color allows the KLI-8023 sensor to beused under a variety of illumination conditions. The imager can be operated in an "Extended Dynamic Range" mode for the most demanding applications.

Pixel Count 8002 x 3

Pixel Pitch 9 µm

Detectors


0.3 0.6 1 2 3 5 7 10 20 30
INTRINSIC/SCHOTTKY BARRIER FOCAL PLANES
Ge
PbS
InSb
Si
PtSi
IrSi
GaAs
HgCDTe
(MCT)
EXTRINSIC FOCAL PLANES
SiZn
Si In
SiAs
SiSe
SiGa
SiSb
TARGETS
HI-ENDO
ICBM RV'S
MID COURSE
BOOST
POST BOOST
SPACE VEH
SPACE VEHICLES
REFLECTED SUNLIGHT
A/C CM
A/C CM
TANKS
TANKS
TANKS
ATMOSPHERIC TRANSMISSION
0.8
0.6
0.4
0.2
0.0
Wavelength (μ)
OPERATING TEMPERATURE (K)
300
160
120
70
40
20
10

Cryo-Coolers

- The use of materials other than silicon requires cooling technologies.
- Miniature 'Stirling Cycle' coolers are a hidden but essential component of remote sensing systems
- Illustration here from AIM, a German company, and a distant subsidiary of Daimler-Chrysler
- Note that a reliability of some 4000 hours is only 5.5 months – not enough for an operational satellite system.

	SL100-10	SC025-12
Cooling Capacity [W] at 80K T_C and 23°C environment temperature	1.25	0.25
Temperature Stabilization	internal electronics	unregulated
Maximum Input Power [W]	65	40
Reliability [h]	> 4,000	> 400
Weight [kg]	2.2	1.3
Compressor Length [mm]	133	143
Compressor Diameter [mm]	60.45	44.44
Coldtip Length [mm]	59.2	55.4
Coldtip Diameter [mm]	13.7	4.86
Maximum Transferline length [mm]	381	230

CryoCoolers

- Cryogenic Linear Drive Stirling Coolers
  - Coldtip Length 59.2 mm
  - Coldtip Diameter 13.7 mm
  - Cooling Capacity: 1.25 W at 80K T_C and 23°C environment temperature
  - Reliability > 4,000 hours
  - Weight 2.2 kg

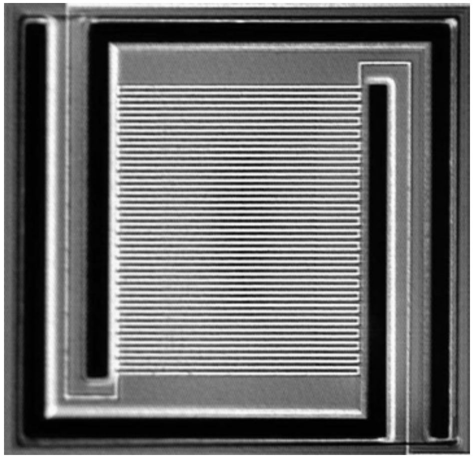
Cooling unit

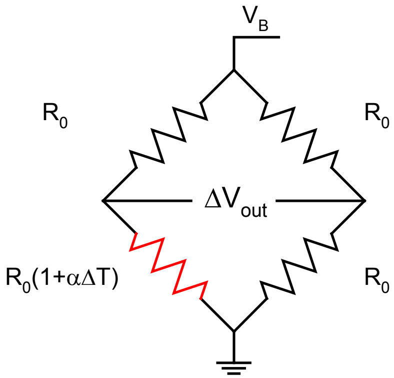
Cold Finger

Un-Cooled Focal Planes

- Micro-Bolometer uses a resistance measuring technique
- Works well for LWIR
- Currently not as sensitive as cooled technologies (higher intrinsic noise)

Thermally Isolated Resistor
(200 x 200 μm^2)

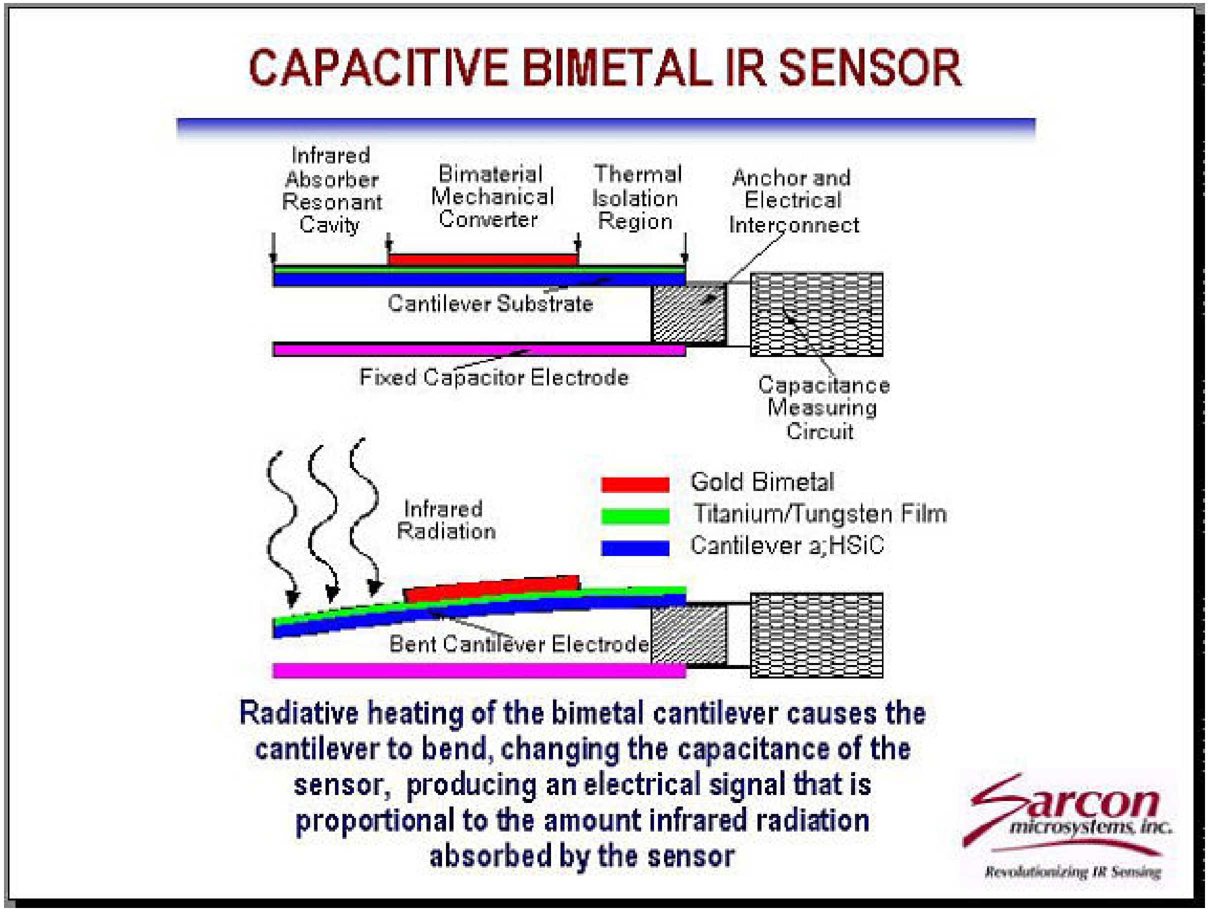




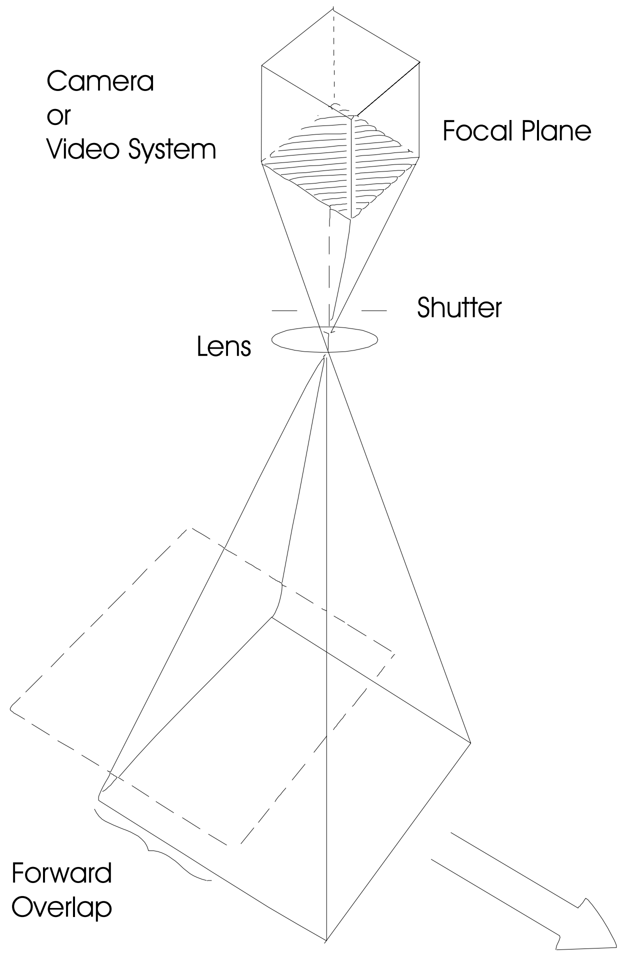
$$\Delta V_{out} \approx \frac{\alpha V_B}{4} \Delta T$$

Un-Cooled Focal Planes

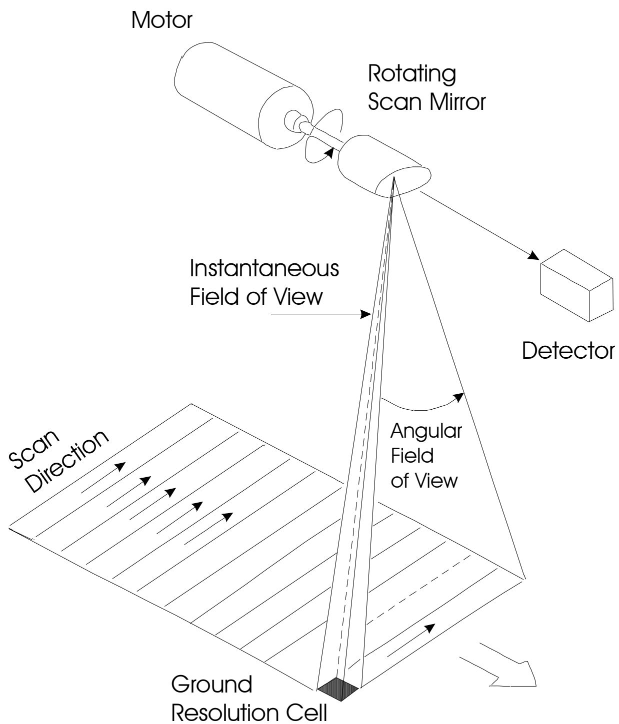
- Capacitive Bimetal IR Sensor
- http://www.sarcon.com/research_&_dev/ir_sensor_concept/slide1.htm



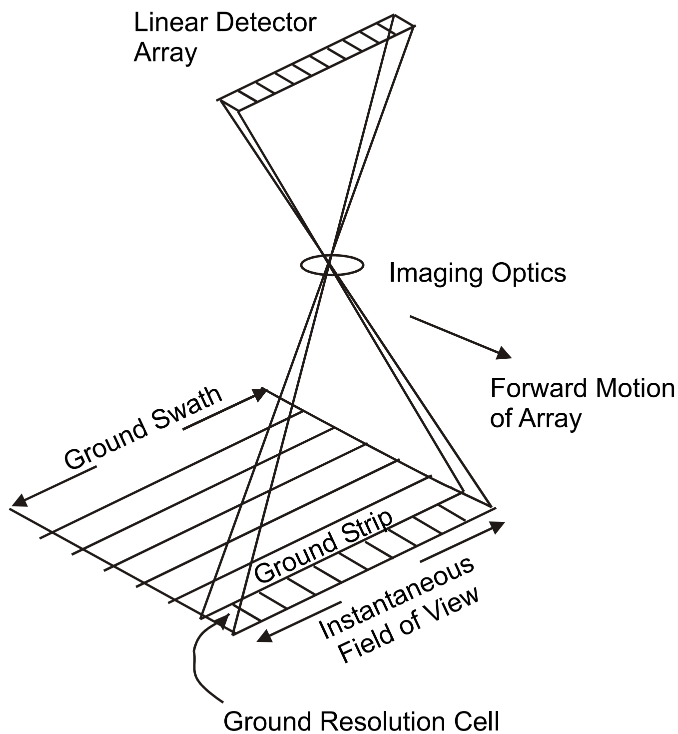
Framing System



Cross-Track Sensor



Pushbroom Sensor



Hubble Deployment

April 25, 1990

Orbital tracking – needs to be located at least every few days

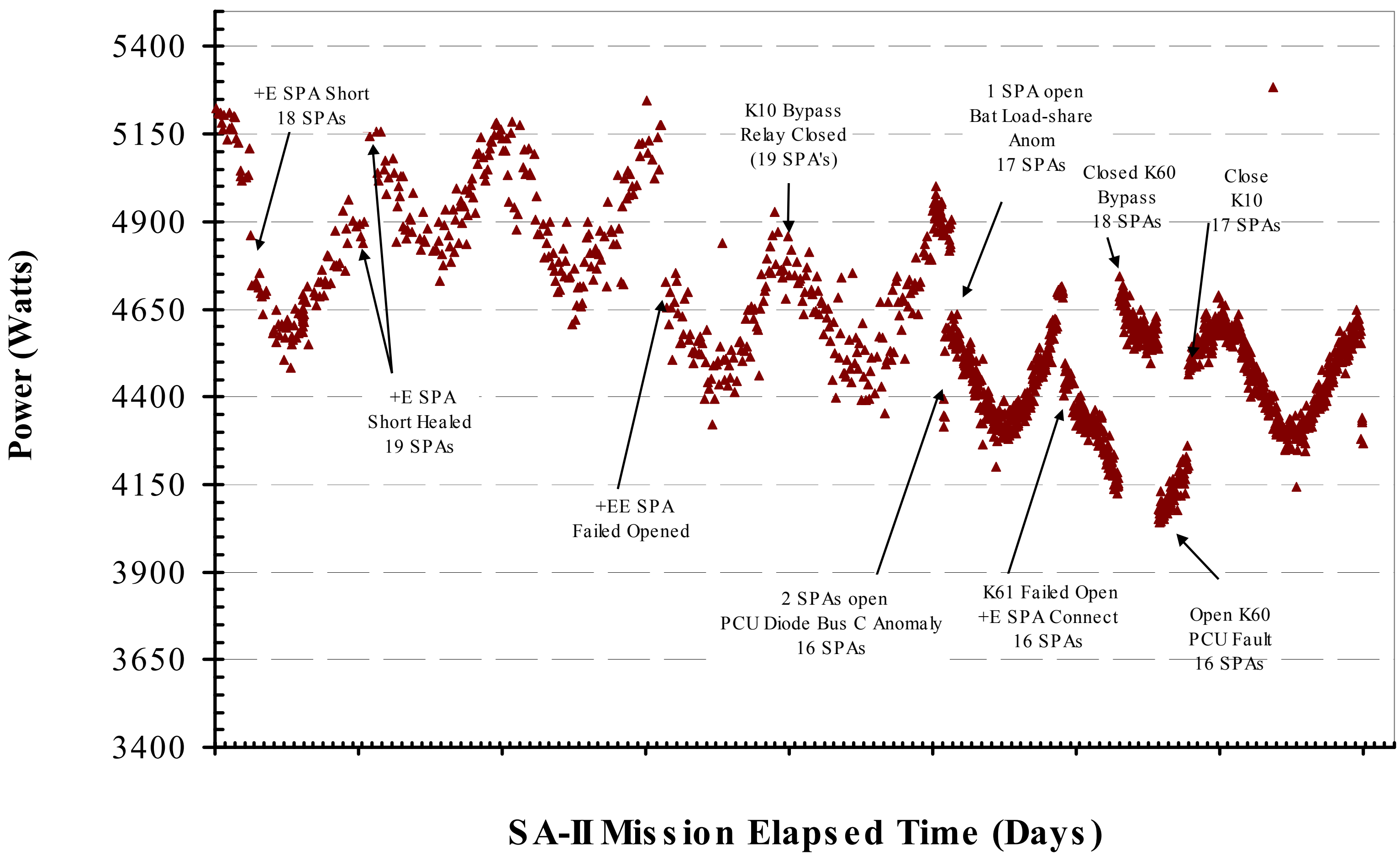
The position error may be as large as 30 km within two days of a determination of the position of the spacecraft in its orbit.

The Hubble Satellite

• Launch Date/Time	1990-04-25 at 12:33:51 UTC
• On-orbit dry mass	11600.00 kg
• Nominal Power Output	5000 W (BOL)
• Batteries	Six – 60 Amp-hour NiMH
• Orbital Period	96.66 m
• Inclination	28.48 degrees
• Eccentricity	0.00172
• Periapsis	586.47 km
• Apoapsis	610.44 km
• Telemetry rates	0.500 - 1000.000 kbps
• Effective Telemetry Rate	4.238 kbps

Hubble Power Systems

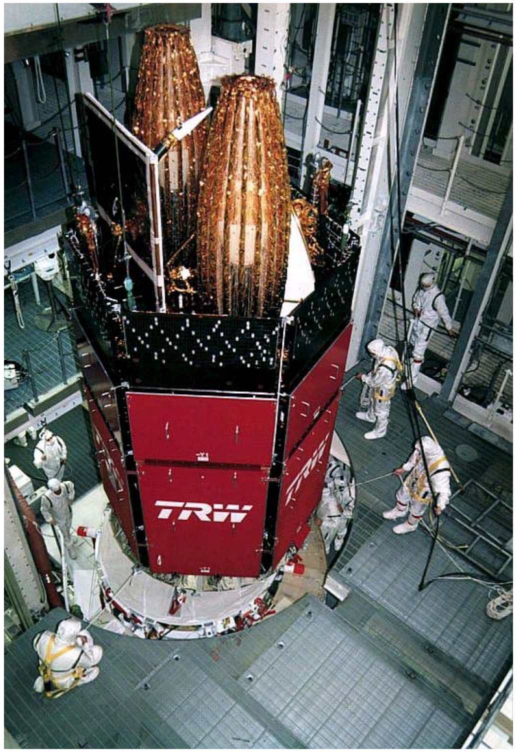
Solar Array II - 1993-2001



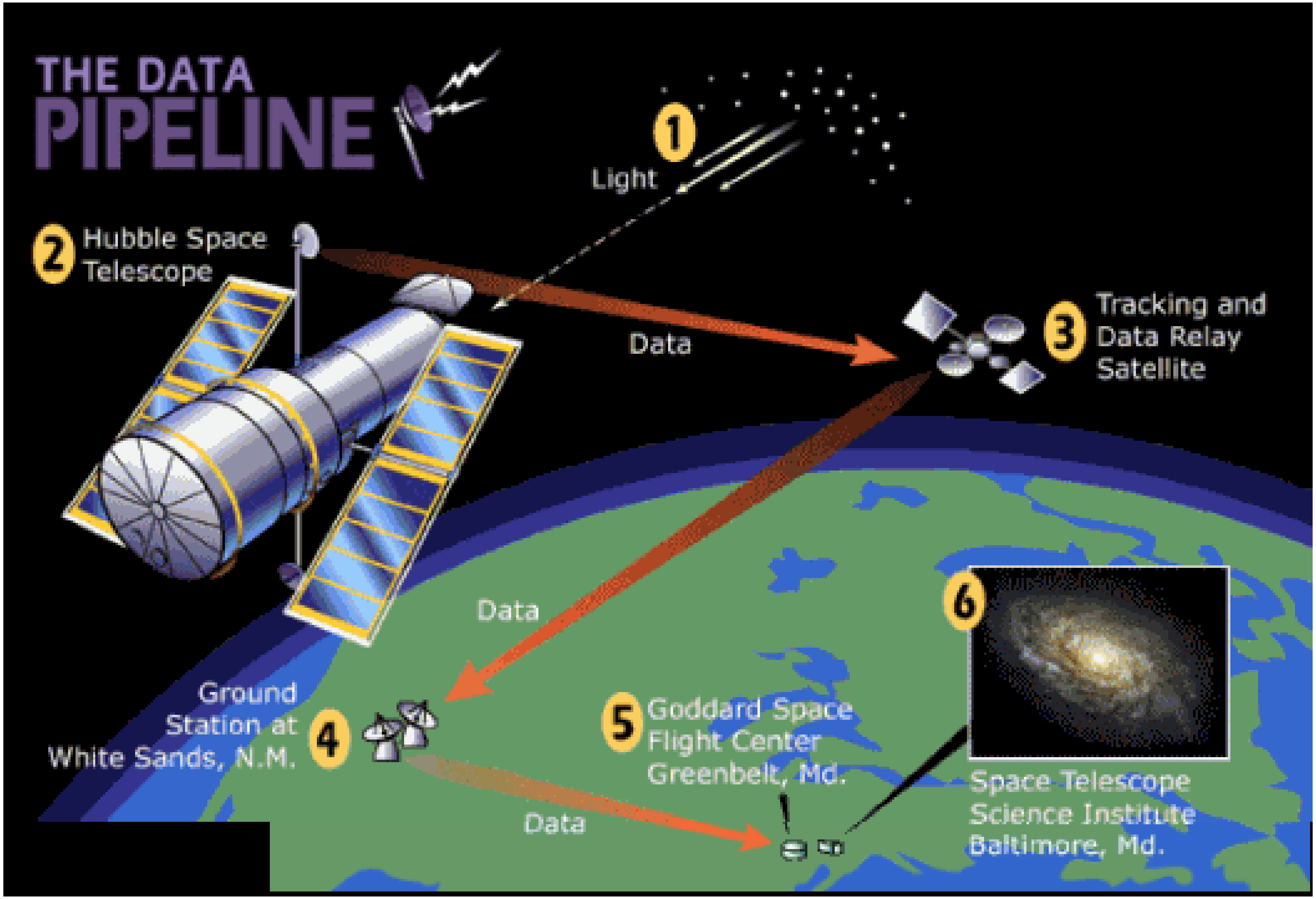
Hubble Telemetry

Tracking and Data Relay Satellite (System)

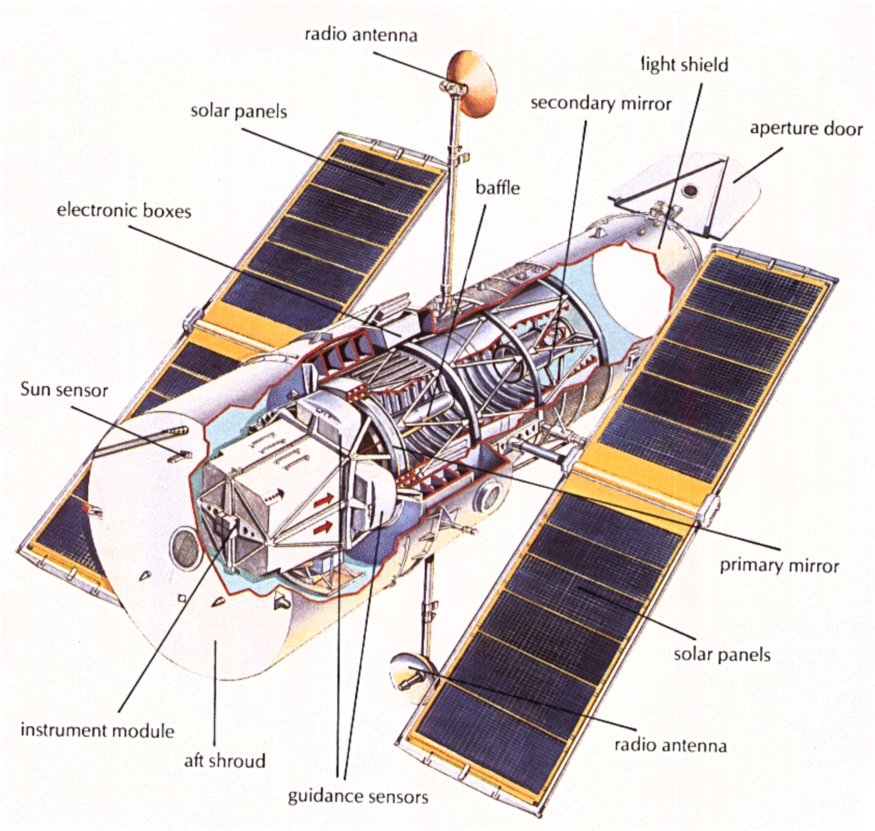
- TDRS (TDRS-7 shown)
- Ground station at White Sands, NM
  - The ground stations include:
    - three (3) 18.3 meter Ku-band antennas,
    - three (3) 19 meter Ku-band antennas and
    - two (2) 10 meter S-band TT&C antennas.

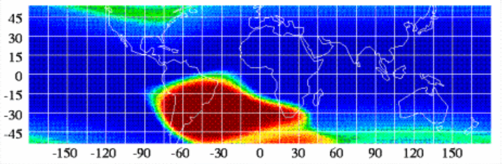


The Data Pipeline



Hubble Diagram





A picture of the relative location of the SAA from NASA. The data were collected by the South Atlantic Anomaly Detector (SAAD) aboard the ROSAT spacecraft. It consists of 10 cm² of Germanium and served as a particle background monitor

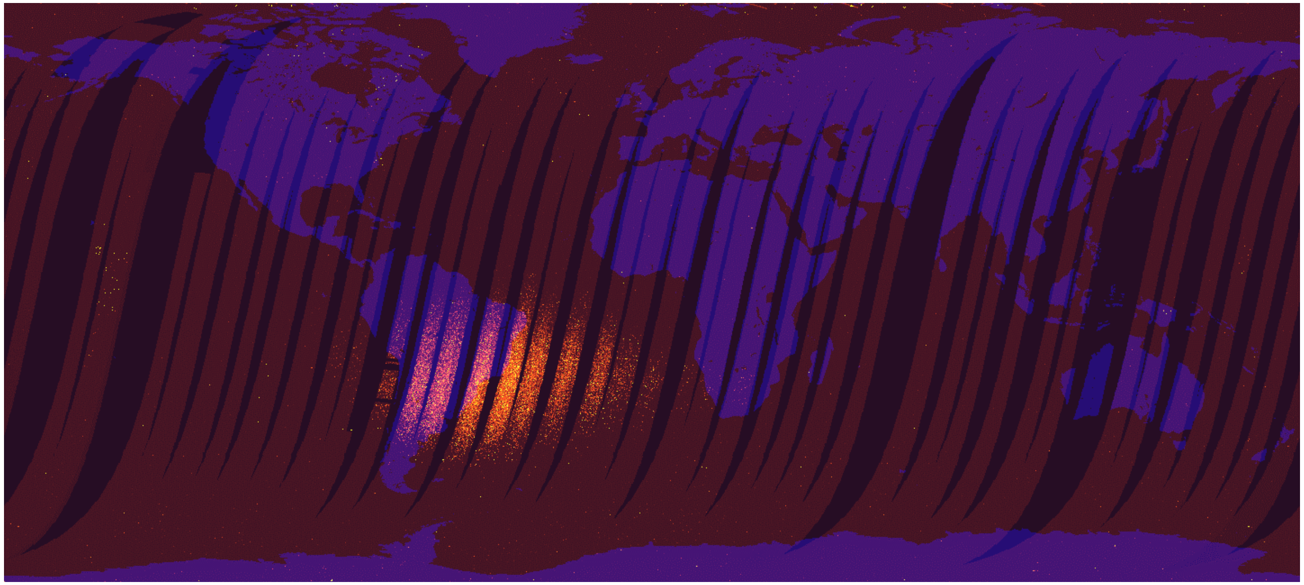
- Solar arrays are 2500 W each; Replaced several times
- Detectors are interfered with by penetrating radiation over South Atlantic Anomaly

Detector Background

- The detector background arises primarily from thermal electrons at the first photocathode and high energy particles. In the 600~km altitude, 28° inclination orbit of HST, substantial fluxes of magnetospheric electrons and protons are encountered in the South Atlantic Anomaly (SAA). The more energetic of these particles are capable of generating intense flashes of Cerenkov radiation in the MgF2 faceplate of the FOC intensifiers. Since this noise source originates as photons at the very front end of the detector, the Video Processing Unit of the FOC is not able to distinguish between real celestial photons striking the cathode and Cerenkov generated photons. The threshold energy for C^ erenkov radiation in MgF2 is E>220~keV for electrons and E>400~MeV for protons. Shielding of 4 mm aluminum or more was built into the design of the FOC in order to prevent electrons of energies E < 3-5~MeV from reaching the detectors from any direction.
- The effects of the SAA on the FOC were extensively mapped during the commissioning phase. The FOC turned out to be considerably less sensitive to SAA electrons than had been feared. This is presumably due to the additional shielding to electrons provided by the rest of the HST spacecraft. The response of the FOC to SAA protons on the other hand is in good qualitative agreement with the expectations-although the sensitivity of the two FOC detectors differs somewhat.
- The highest background rates (0.2~counts pixel-1 s-1 in the F/48 during nominal operations and 0.02 counts pixel-1 s-1 in the F/96) are encountered over South America within the peak of the SAA proton density distribution. Since these rates are not high enough to cause damage to the FOC detectors, the FOC is kept fully operational during SAA passages. However, such high background rates do exclude useful scientific observations. A ground-track contour delineating the observed region of high background has been installed within the HST ground system in order that FOC observations not be scheduled within it. Users of the FOC need therefore not concern themselves with avoiding the SAA under normal circumstances (*i.e.*, periods not having unusually high solar activity).
- The typical detector background rates experienced well outside the SAA are 7.0 × 10-4 counts pixel-1 s-1 in the detector for the F/96 relay and 10-2 counts pixel-1 s-1 in the detector for the F/48 relay. Upward fluctuations of a factor ≈3 from these minimum values are, however, seen throughout the HST orbit. The minimum in-orbit background rates are, respectively, factors of ≈5 and ≈3 higher than the background rates measured during ground testing implying that the bulk of detector background counts are particle induced.

Terra Satellite Anomalies in LEO

- **The South Atlantic Anomaly (SAA)**. Even before the cover opened, the Multi-angle Imaging SpectroRadiometer (MISR) instrument aboard NASA's Terra spacecraft began making scientific measurements. The MISR cameras, designed to detect visible light, are also sensitive to energetic protons at high altitudes. With the cover closed, background levels of protons stand out.
- This map was created by specially processing MISR "dark" data taken between 3 February and 16 February 2000, while the cover was still closed. Data from the red band of the most forward-looking MISR camera were geographically projected over a map of Earth's land areas. Individual orbit tracks are visible, and some tracks are missing due to data gaps, missing spacecraft navigation information, or other early-mission processing problems. Each picture element is a square measuring one-quarter of a degree in latitude and longitude, and each contains hundreds to thousands of pixels from the raw MISR imagery. The South Atlantic Anomaly (SAA) is a region of unusually high proton levels. Because proton "hits" even in the SAA are relatively infrequent, each picture element of the map shows the most extreme "outliers" resulting from proton hits, rather than the average of all observations. This accentuates the effect of the SAA.
- http://eosweb.larc.nasa.gov/HPDOCS/misr/misr_html/darkmap.html

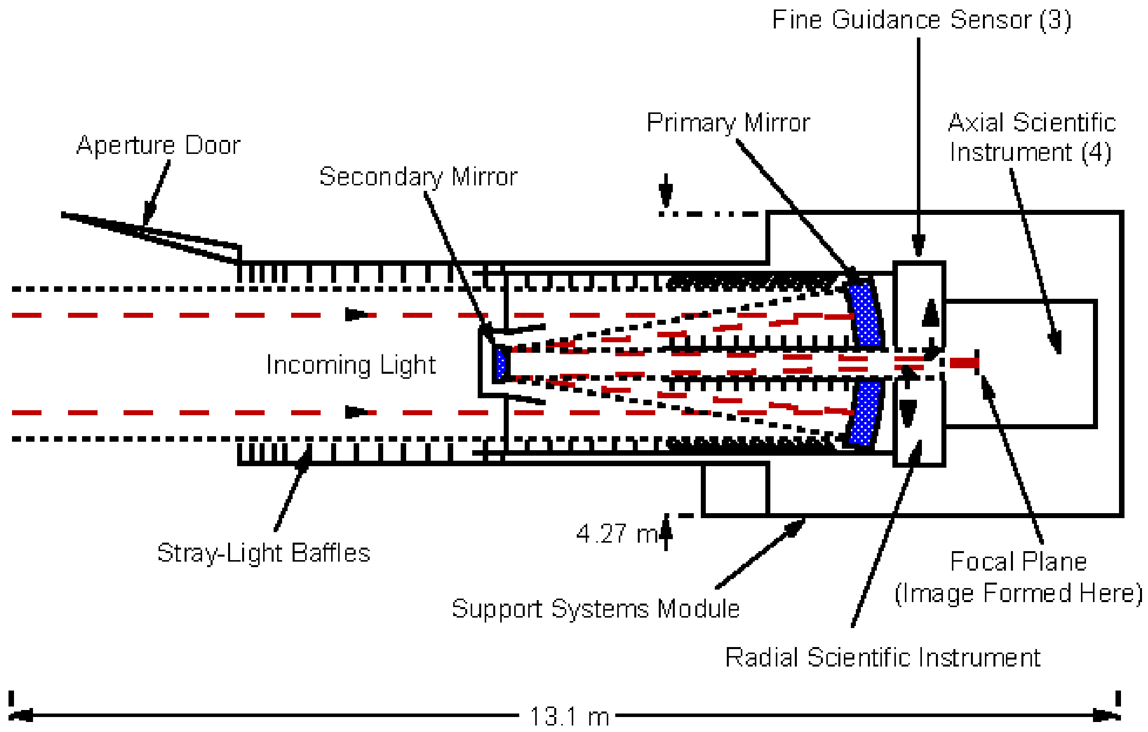


Hubble - 1997

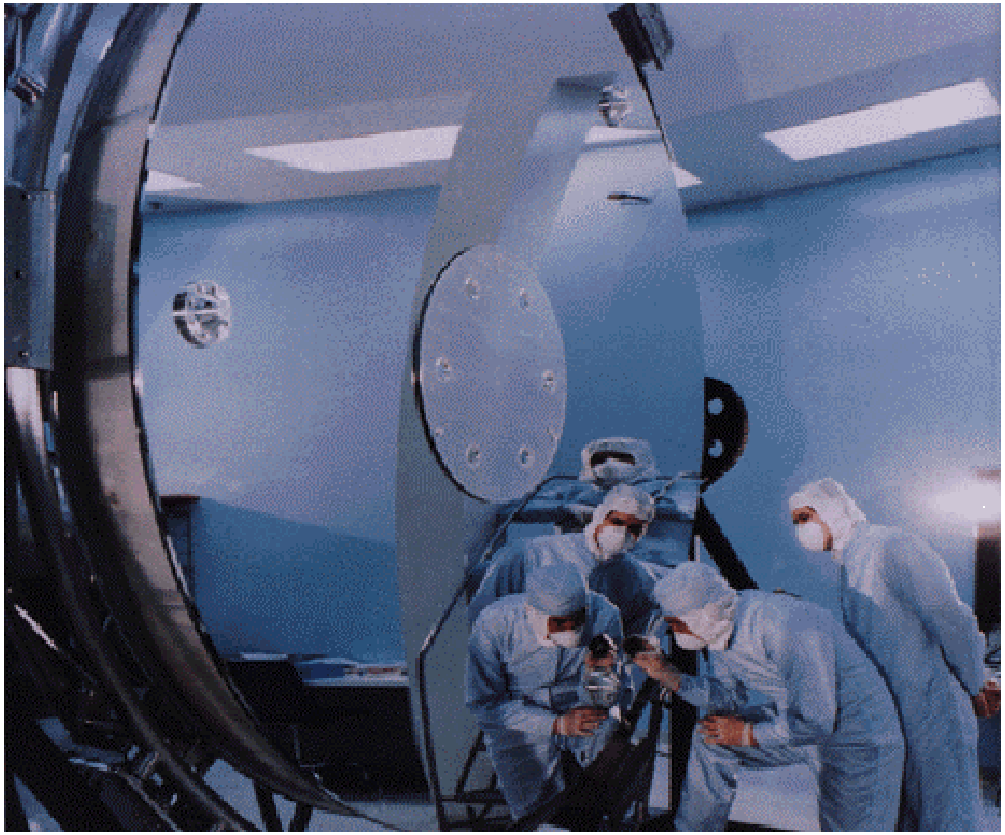
- 2.4 m diameter mirror, f/24 Ritchey-Chretien Cassegrain.
- The angular resolution at 500 nm is 0.043 arc-seconds (0.21 μ-radians).
- Hubble has a pointing accuracy of 0.007 arc-seconds (0.034 μ-radians).

Hubble Optics

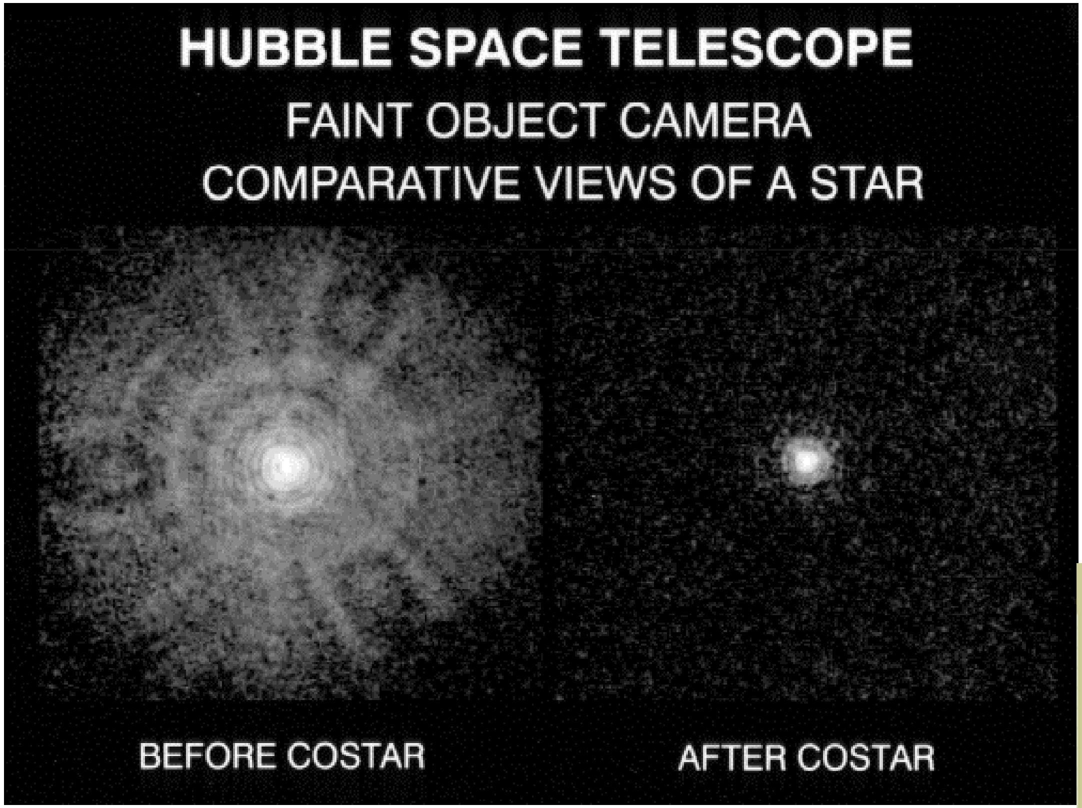
- 2.4 m diameter mirror, f/24 Ritchey-Chretien Cassegrain.
- Mirrors are hyperboloids
- Primary: 57.6 m focal length
- Distance Between The Two Mirrors = 4.6 m
- Focal Plane Distance (from front of primary mirror) = 1.5 m

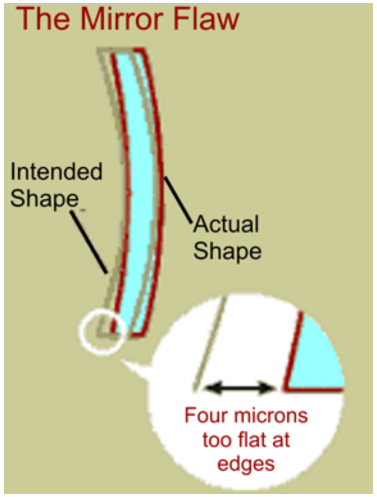


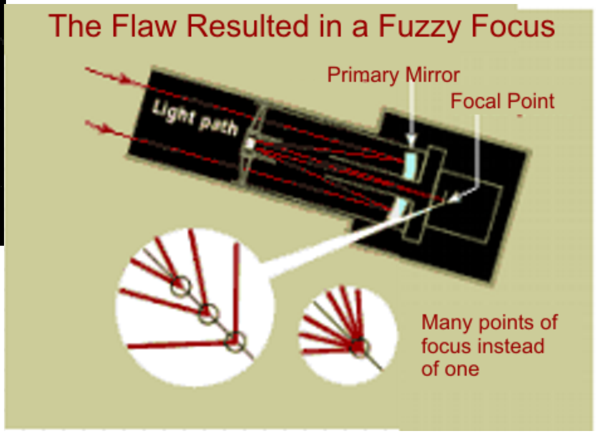
Hubble Mirror



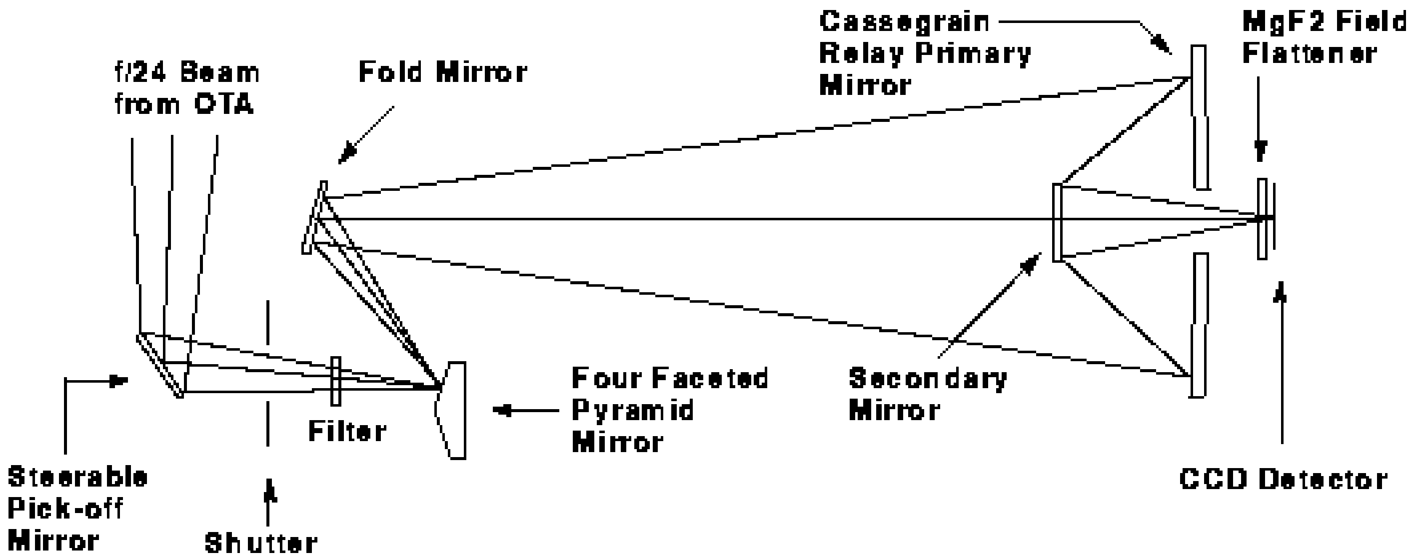
Hubble Aberrations



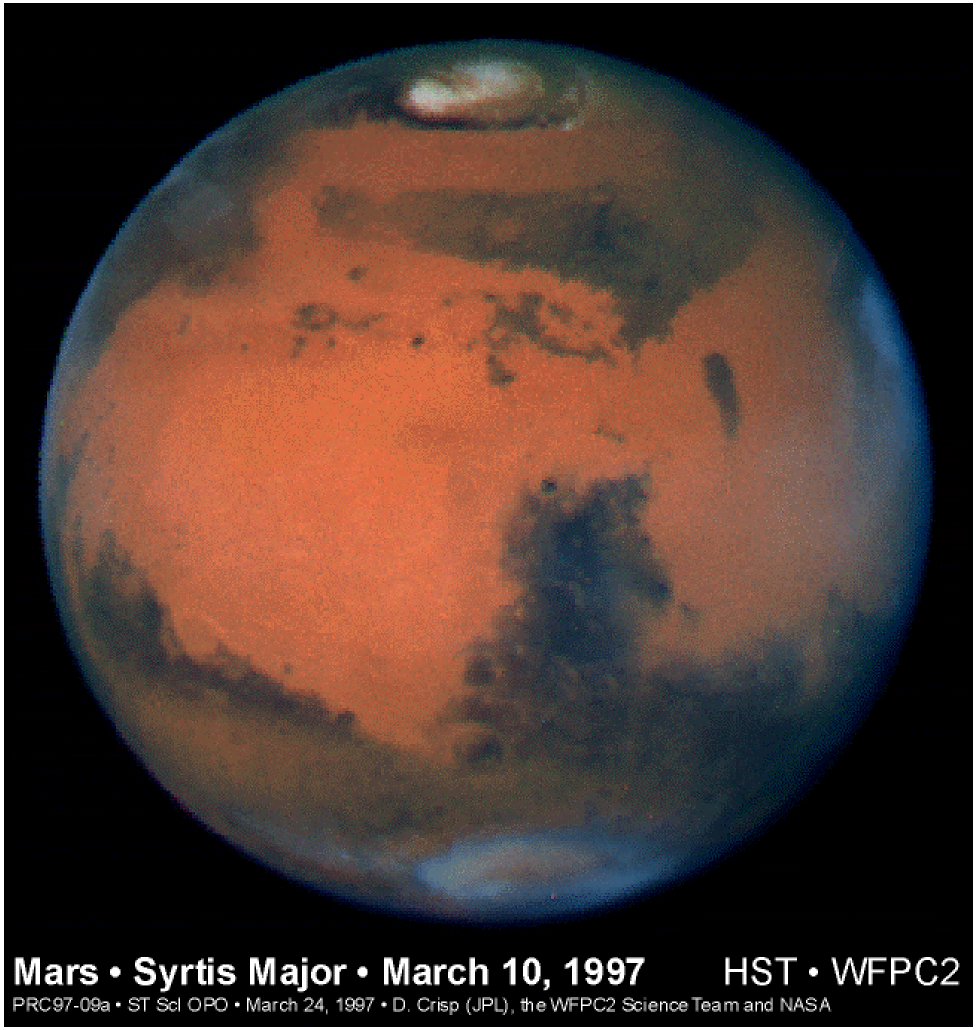




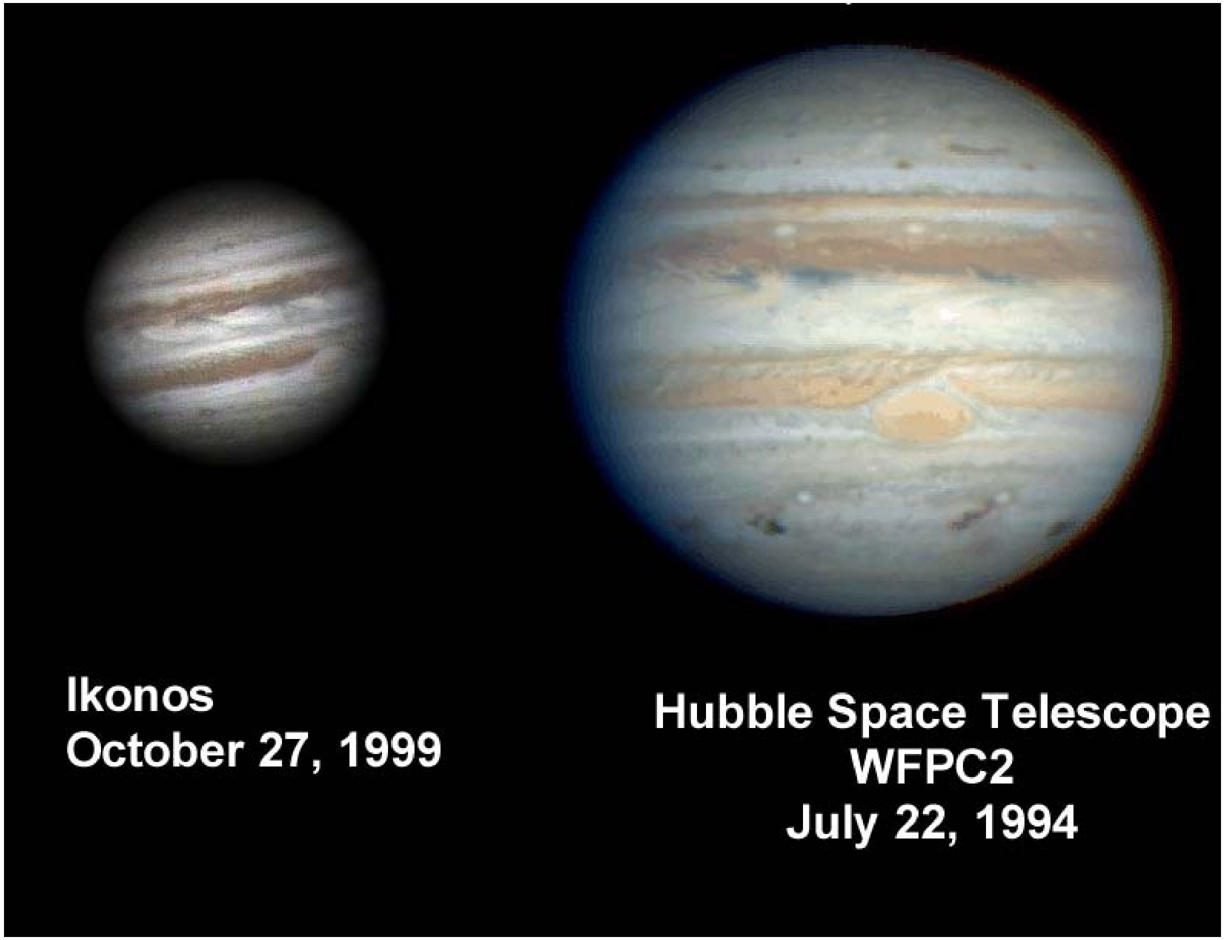
WFPC2


Cassegrain Relay Primary Mirror
MgF2 Field Flattener
f/24 Beam from OTA
Fold Mirror
Four Faceted Pyramid Mirror
Secondary Mirror
Filter
Steerable Pick-off Mirror
Shutter
CCD Detector

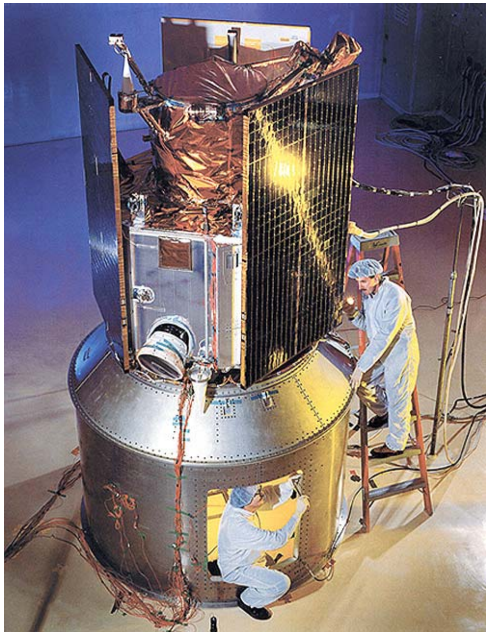
Hubble - Mars

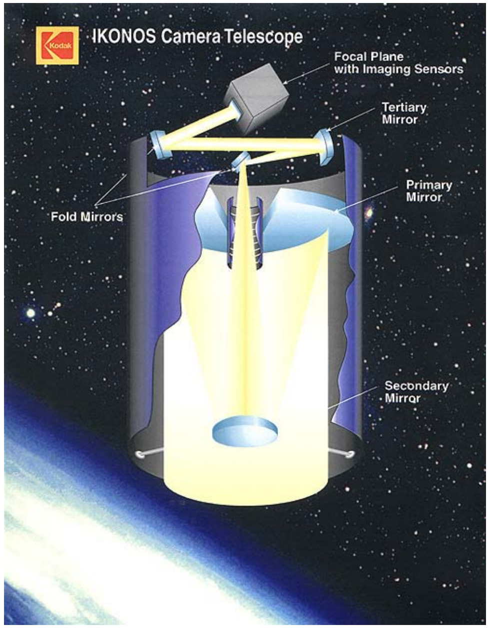

Mars • Syrtis Major • March 10, 1997 HST • WFPC2
PRC97-09a • ST ScI OPO • March 24, 1997 • D. Crisp (JPL), the WFPC2 Science Team and NASA

IKONOS vs Hubble - Jupiter



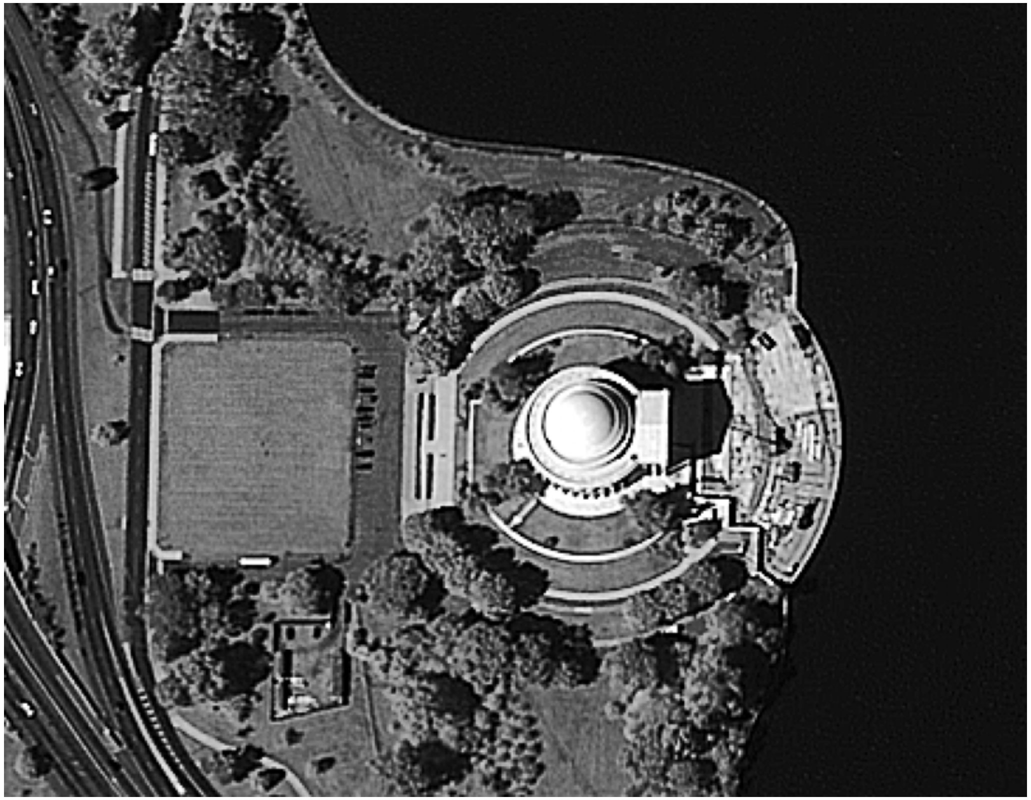
IKONOS





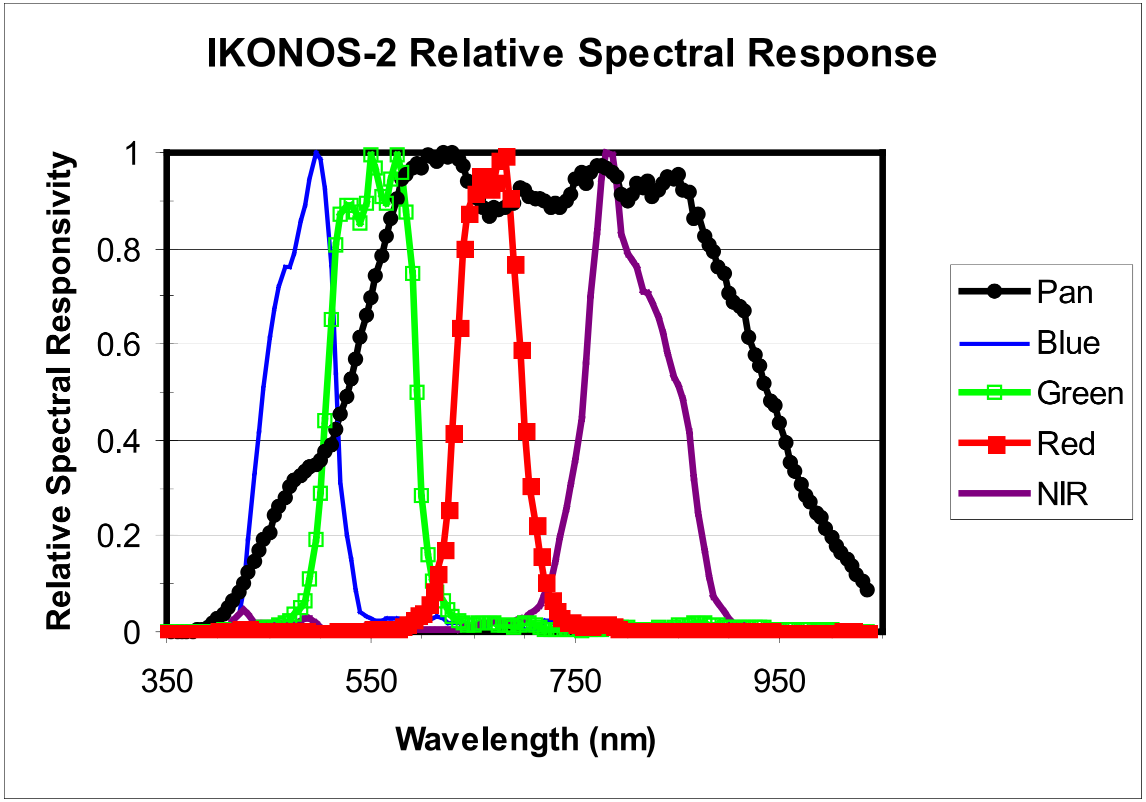
- Telescope was built by Kodak
- Obscured, three mirror anastigmat with two fold mirrors:
  - 70 cm diameter primary with 16 cm central hole;
  - 10.00 m focal length, f/14.3
  - 1.2 μrad Instantaneous field-of-view (pixel),
- Focal Plane Unit
  - Panchromatic sensor: 12 micron pixel pitch, 13,500 pixels
  - Multispectral sensor: 48 micron pixel pitch, 3375 pixels
- Digital Processing Unit
  - Compression rate: 11 bits per pixel compressed to 2.6 bpp
  - Compression speed: 4 million pixels per second per processing channel

IKONOS – First Light



- The world of remote sensing changed dramatically on September 24, 1999, with the successful launch of the IKONOS satellite by the Space Imaging company
- The Washington DC image was taken September 30, 1999.

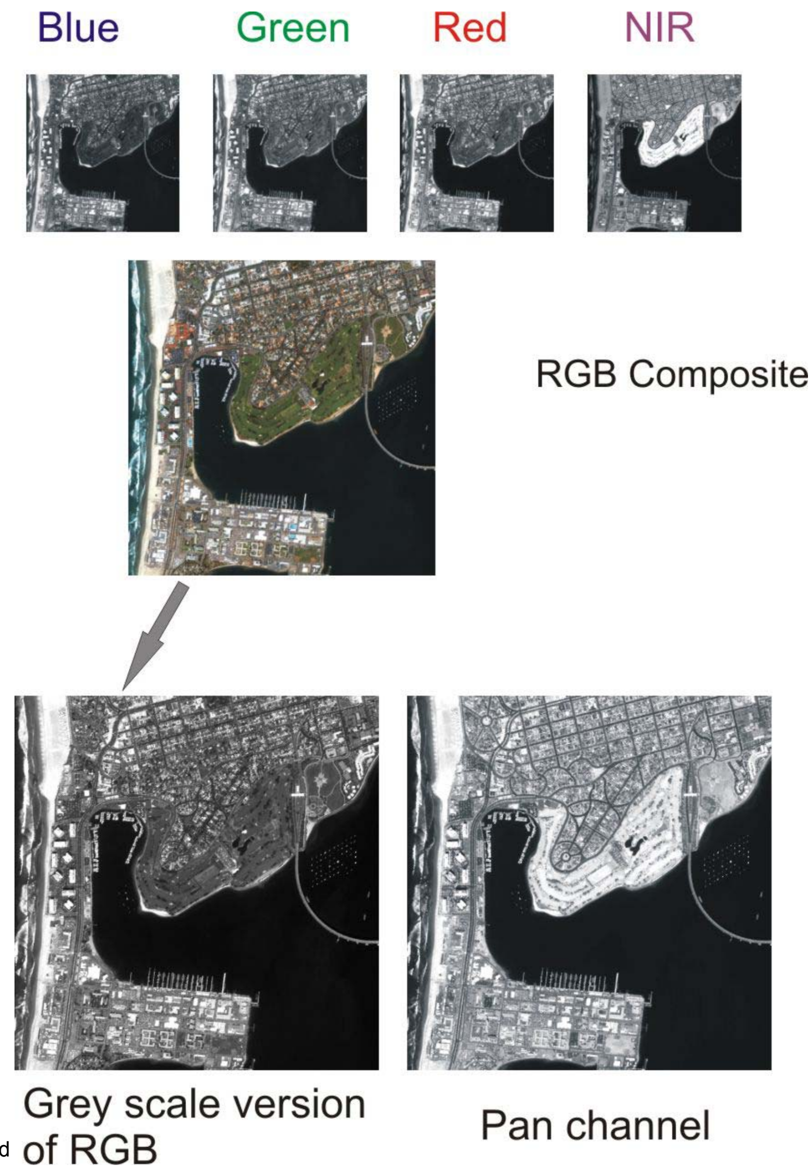
IKONOS – Spectral Response



- 4 color bands, one panchromatic band, at 4 and 1-meter resolution, respectively.
- Note that the panchromatic band is <u>not</u> sensitive in the blue portion of the spectrum, but has a significant response in the near-IR.

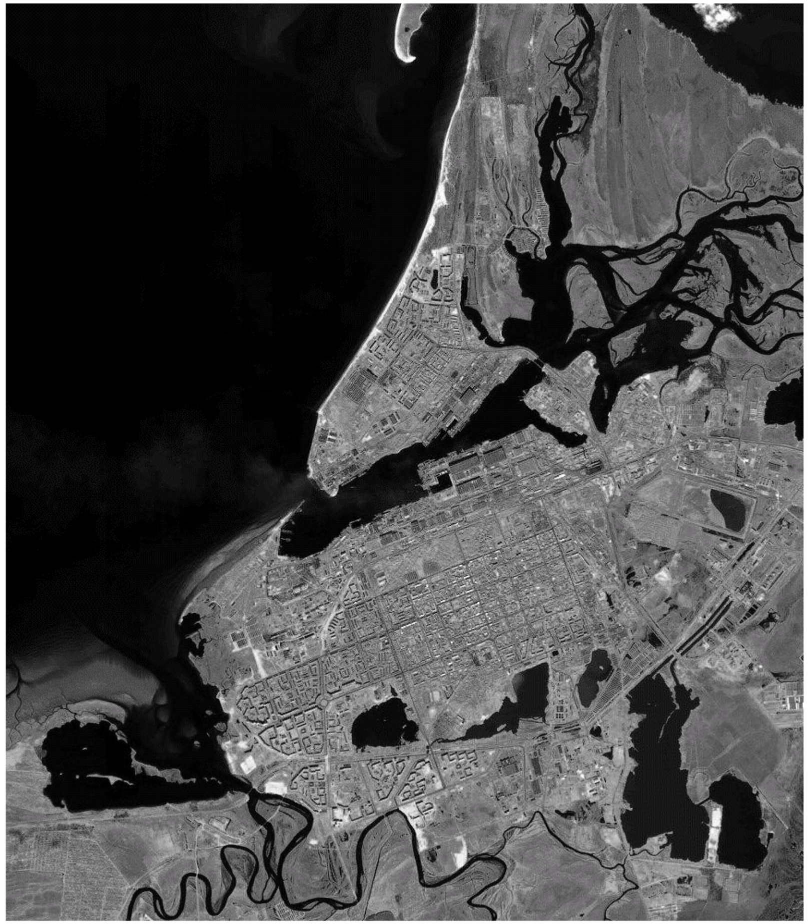
Pan Sensor – IR sensitivity

- The panchromatic sensor has a spectral response which is low in the blue, but significant in the NIR.
- As a consequence, vegetation is bright.



This is what you would get with b&w film

Severodvinsk - Overview



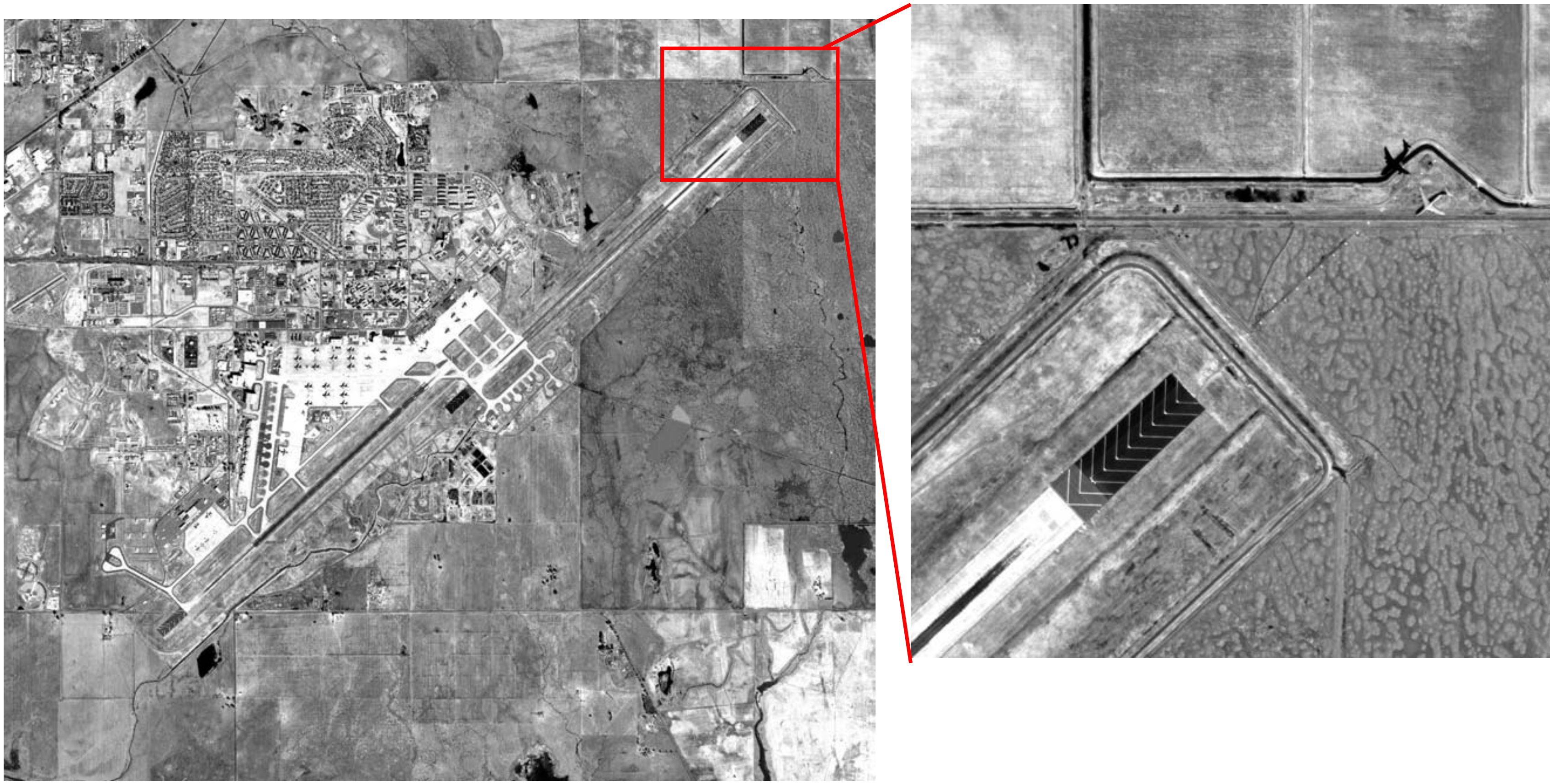
IKONOS - June 13, 2001

Severodvinsk – Navy Yard

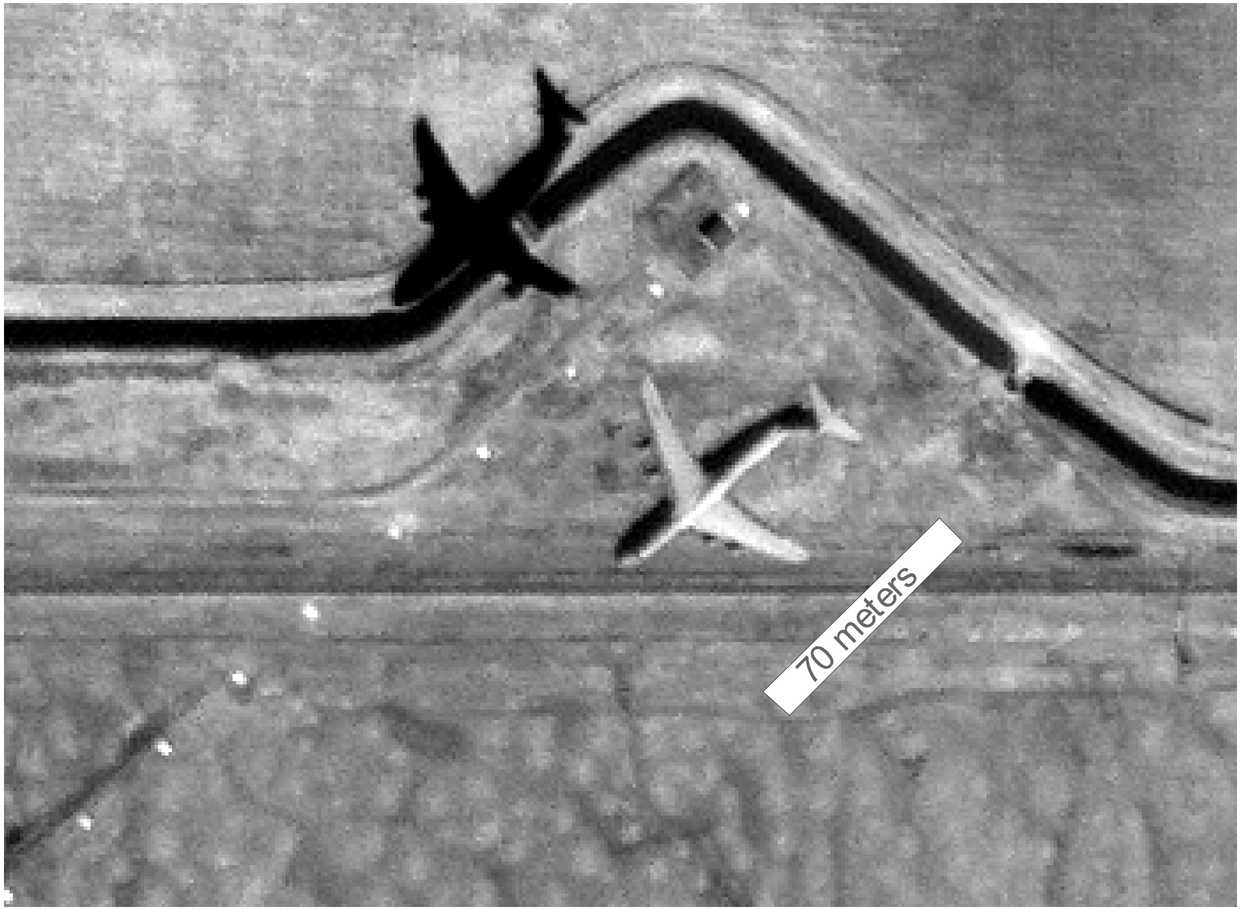
IKONOS Telemetry, Orbit

- Telemetry
  - 64 Gbits onboard storage
  - X-band downlink at 320 Mbps
  - Multiple Ground Stations
- Orbit
  - Altitude: 681 kilometers / 423 miles
  - Inclination angle: 98.1 deg,
  - Sun-synchronous
    - Descending nodal crossing time: 10-11 a.m.
  - Period: 98 minutes

Travis AFB



Transport Airplane



- The effective “shutter speed” of the sensor is quite fast – effectively less than a milli-second.
- You can measure the height of the airplane by looking at the shadow, and since you know the distance to the touchdown point, things like air-speed.

Exposure Time

For a satellite moving at 7 km/s, what must the exposure time be?

- Assume: the satellite can't move more than a portion of 1-meter during the exposure
- For a 1-meter pixel, that means less than 0.14 milli-seconds.
- Rule of thumb for CCD devices is they are roughly as sensitive as ASA 100 film
- Old photography rule – exposure time in seconds is ~ 1/ASA at f/11-f/16
- IKONOS is f/14.3, so the exposure time ought to be ~10 milli-seconds.
- How do you fix this?
- Time-Domain-Integration (TDI) on the chip
  - This allows for a wider dynamic range response for the sensor (brightness variations)
  - It provides greater sensitivity (shorter effective exposure times)

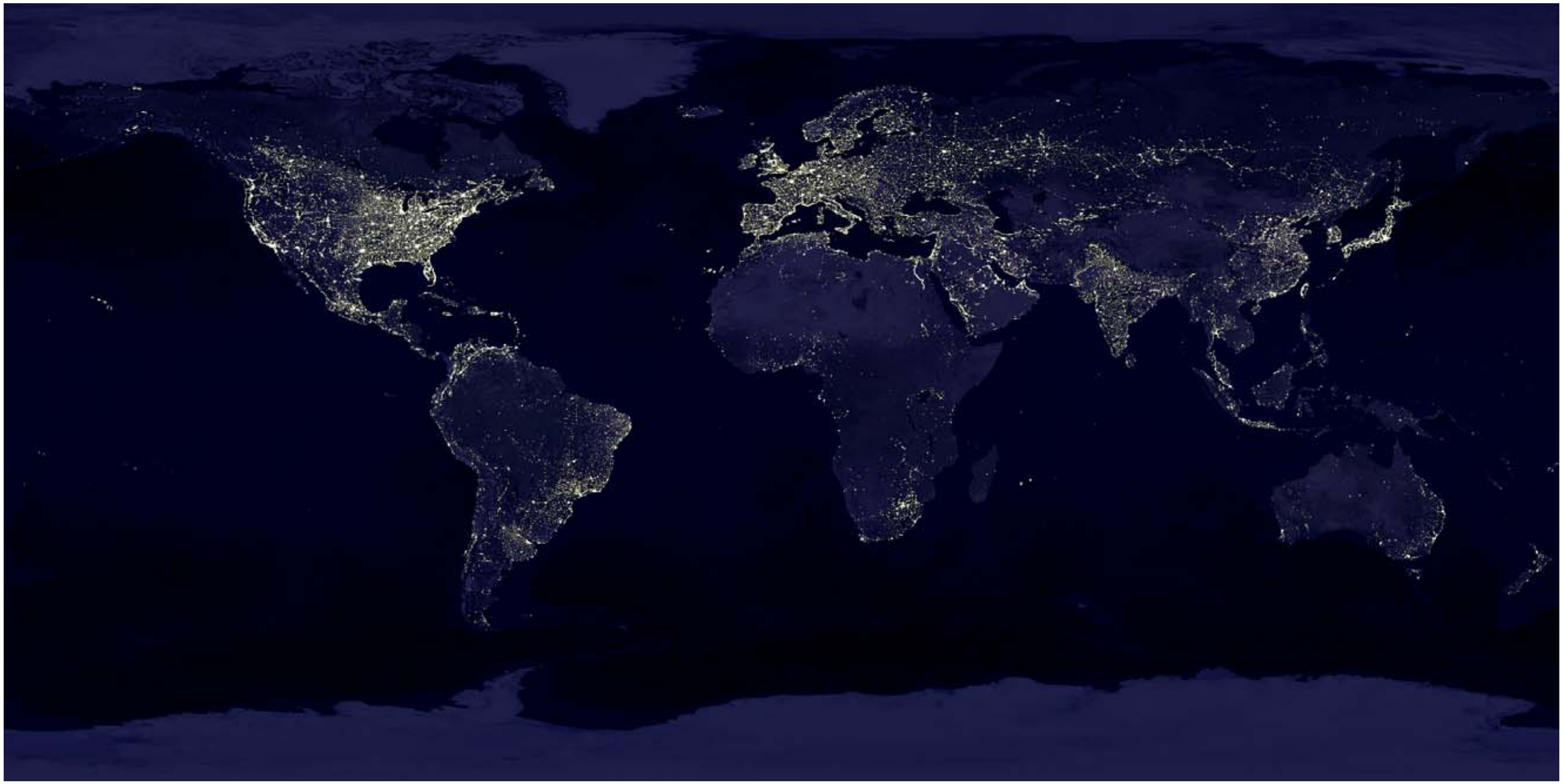
DMSP – US at Night

DMSP - OLS

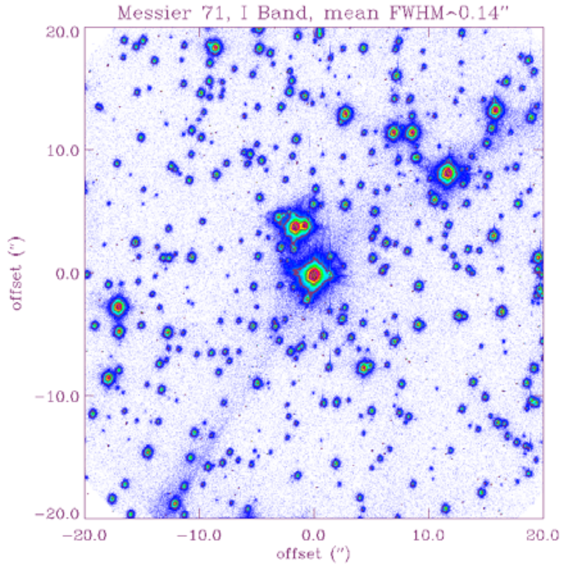
- The OLS instrument consists of two telescopes and a photo multiplier tube (PMT). The scanning telescope of the OLS has a 20-cm aperture with an effective collecting area of 239 cm^2 and effective focal length of 1.22 m.
- Telescope pixel values are replaced by Photo Multiplier Tube (PMT) values at night. A PMT pixel is 2.7 km at nadir.
- Swath (Scan Angle): 3000km @ 833km altitude

DMSP – Europe at Night

DMSP – World at Night



PUEO's second engineering run images



This is an image of the center of the globular cluster M71 at I band (830 nm). FWHM is 0.10 arcsec (center) to 0.18 arcsec (edges). The natural seeing was 0.30 arcsec (excluding tracking errors and telescope fixed aberrations). This is a 1200 seconds exposure.

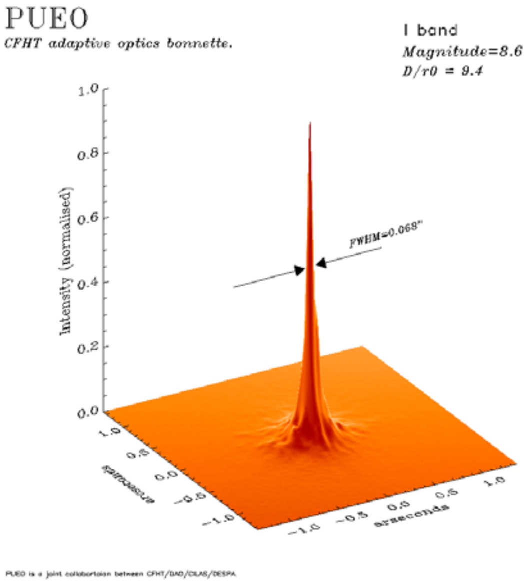


Image of a 8.6 R magnitude star in the I band. The FWHM is 0.068 arcsec. To our knowledge, this is the crispiest long exposure image ever from ground based observations. The Strehl ratio is 13\%. Integration time is 2 seconds, which is kinda short but is sufficient to get a meaninful average in close-loop. D/r0 is 9.4 at 0.5 microns.

May 3-8, 1996, Canada-France-Hawaii Telescope (CFHT) adaptive optics compensation system. Also called PUEO after the sharp vision Hawaiian owl. The telescope is 3.6 meter in diameter. The observatory is located atop the summit of Mauna Kea, a 4200 meter, dormant volcano located on the island of Hawaii.